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# DEMO6 - dD6.6 Halfway assessment of smart solar district

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**• Short Description**

This deliverable aims at presenting the halfway assessment of the demonstrator: installations on site, experiment and first results. Storage assets, PV panels, measurement devices and OLTC transformer are presented.

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# 1 Introduction and scope of the document

## 1.1 Scope of the Document

This document aims at presenting the halfway assessment of demo 6, covering the measurement devices, the storage assets, the OLTC transformer and the recruitment process. First results are presented: power flow computations, harmonics measurements, battery efficiency. Results of battery testing are also presented.

## 1.2 Structure of the Document

The document is organized in **three main sections**

The **first section** covers the measurements **and first results related to measurement devices**. Section 2.1 covers the assessment of harmonics injection, relying on an advanced metering infrastructure installed on the grid by EDF R&D. Section 2.2presents the different measuring devices installed on site on the main findings related to them. Power flow computation and principles on the low voltage grid are also presented.

The second section describes the **laboratory tests and first installations of devices on the grid: grid batteries, residential batteries and OLTC transformer**. Section 3.1 gives a feed back of the first large scale storage asset installed on site. Section 3.2 is a report of the laboratory testing of the 33 kW battery container which will be installed on site near Cailletiers and Colombie secondary substation. Section 3.3 is a report of the laboratory testing of the residential battery. Section 3.4 presents the main principles and the actual status of the On Load Tap Cha nger transformer to be installed at Cailletiers secondary substation

The **third section** is an **assessment of the PV onsite installation**, including the presentation of the different offers by EDF

## 1.3 **Acronyms**

| | |
|---|---|
| ACR | *Agence Conduite Régionale* = Regional Control Center |
| AGDP | Automatic Grid Disconnection Protection. |
| AID or AIP | Anti-Islanding Device or Protection |
| AMEPS | *Agence de Maintenance et Exploitation des Postes Sources* = Agency for maintenance and operation of primary substation |
| AREX | *Agence d'Exploitation Réseau* = Agency for grid operation |
| BMM | Batteries Management Module (SAFT) |
| BPL | Broadband over Power Lines (Modem ALSTOM) |
| BPL | Broadband over Power Lines (Modem ALSTOM) |
| CAN | Controlled Area Network |
| CB | Circuit Breaker |
| DEIE | *Dispositif d'Echange d'Information d'Exploitation* = device used to opean remotely the main circuit breaker of the storage asset |
| DREAL | *Direction Régionale de l'Environnement, de l'Aménagement et du Logement* = Regional Directorate for Environment, Planning and Housing |
| DSO | Distribution System Operator |
| ECSE | Energy Converter & Storage Equipment (SOCOMEC Converter + SAFT Batteries) |
| EMS | Energy Manager System (~NEM & NBA in the Nice Grid Project) |
| ESSU | Energy Storage System Unit (SAFT String Batteries) |
| FCU | Field Control Unit (ALSTOM) |
| FSS | Fire Safety System. |
| GDP | General Distribution Panel. |

| | |
|---|---|
| HMI | Human Machine Interface. |
| HVAC | Heating Ventilation Air Conditioning. |
| ICPE | Classified Installations for the Protection of Environment |
| IMD | Maximum Discharge Current. |
| IMR | Maximum Charge Current (max 5 seconds). |
| IMR_C | Maximum Continuous Charge Current. |
| LBS | Load Break Switch. |
| LV | Low Voltage |
| LVGB | Low Voltage Grid Battery |
| MBMM | Master Batteries Management Module (SAFT) |
| MCU | Master Control Unit (ALSTOM) |
| MV | Medium Voltage |
| NBA | Network Batteries Aggregator (which controls the operation of grid batteries) |
| NEM | Network Energy Manager |
| PCB | Parallel Circuit Breaker |
| PCS | Power Converter System |
| PCS² | Power Converter & Storage System (SOCOMEC) |
| PDO | Process Data Object (CANOpen) |
| PLC | Power Line Communication Carrier |
| PSB | Primary Substation Battery |
| PV | PhotoVoltaic |

| | |
|---|---|
| RPDO | Received Process Data Object (CANOpen) |
| SC | Short-Circuit |
| SDO | Service Data Object (CANOpen) |
| SMU | Safety and Monitoring Unit (electronic board inside each battery module) |
| SOC | State Of Charge of the batteries. |
| SOH | State Of Health of the batteries |
| SOH | State Of Health of the batteries. |
| SPD | Surge Protection Device. |
| SSB | Secondary Substation Battery |
| TSDO | Transmitted Service Data Object (CANOpen) |
| TSO | Transmission System Operator. |
| UPS | Uninterruptible Power Supply. |
| VFRT | Voltage Fault Ride Through |
| VMD | Maximum Charge Voltage |
| VMR | Minimum Discharge Voltage |

# 2 Assessment of harmonics injection and decentralised voltage control functions

## 2.1 Halfway assessment of harmonics injections

### *2.1.1 Harmonics injection in a substation with a lot of connected PV production*

- **Context**

The realization of Smart Grids, able to accept many low power producers and to implement flexibility both in network operation and load management, is facing news challenges in terms of power quality. Indeed, such networks are based on numerous innovations in various fields, including in particular the power electronics. Consequences in terms of wave quality are strong because power electronics-based systems cause harmonics and distributed generation in general increases the stress on LV voltage control within +/- 10%.
Quality can also be degraded when the short circuit power available is low – especially during islanding – or when there is a risk of voltage harmonic resonances. Nice Grid demonstrator allows an overall assessment of the true quality of the supplied electric wave and impacts of new uses on the electric wave.
To assess the quality of the electric wave, it is necessary to measure voltage, current and harmonics at different points of the network.
The purpose of this chapter is to evaluate the temporal correlation between the harmonic over-voltages observed and the photovoltaic generation at the Dock Trachel HV/LV substation, especially after the connection of a 140 kWp PV generator. Harmonics on the network are measured before and after the connection of this new PV generator to analyze its effects.

- **Instrumentation**

Measurement equipment (Alptec 2444i) has been installed at the Dock Trachel substation for over a year to measure variations of power demand (3s aggregation points) to determine the performances of the future battery inverters or other islanding systems and to measure harmonic voltages and currents at the station.
Currently, the data reported are:

- 10 minute interval harmonics up to the $50^{th}$ rank,
- 3 second interval following data:
  - Single voltage $V_{1Mean}$
  - Single voltage $V_{2Mean}$
  - Single voltage $V_{3Mean}$
  - Phase-phase voltage $U_{12Mean}$
  - Phase-phase voltage $U_{23Mean}$
  - Phase-phase voltage $U_{31Mean}$
  - Frequency $f_{1Mean}$
  - Frequency $f_{2Mean}$

- Frequency $f_{3Mean}$
- Active power $P_{1Mean}$
- Active power $P_{2Mean}$
- Active power $P_{3Mean}$
- Active power $P_{TriMean}$
- Reactive power $Q_{1Mean}$
- Reactive power $Q_{2Mean}$
- Reactive power $Q_{3Mean}$
- Reactive power $Q_{TriMean}$

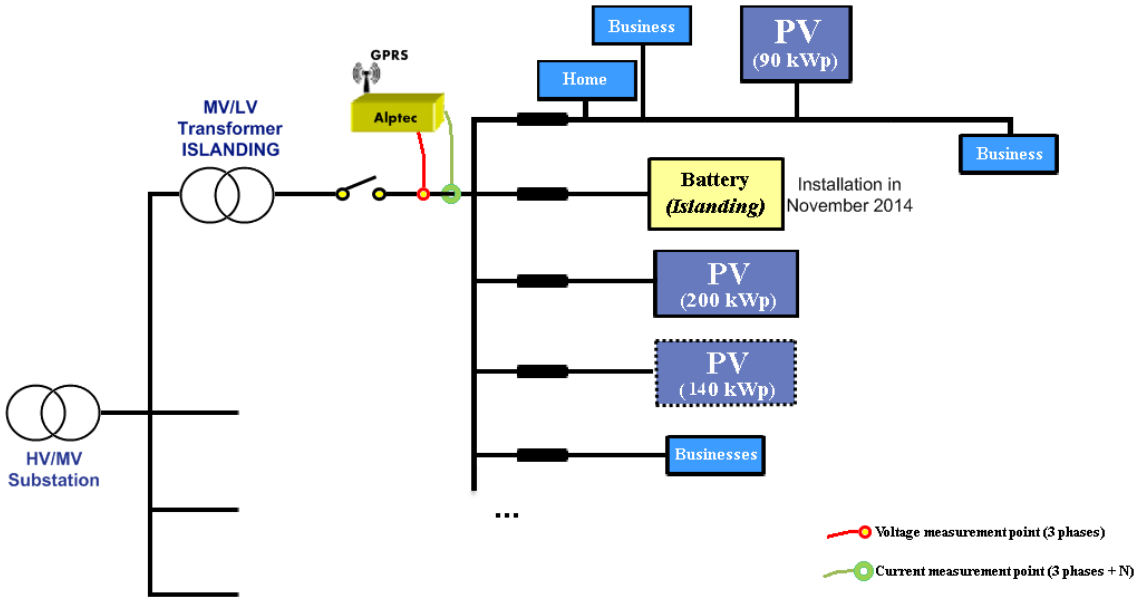



*Figure 1: Instrumentation diagram of the Dock Trachel substation*

On Figure 1, each PV generator corresponds to the sum of small three-phased PV production units with a power from 10 to 15 kWp. So, the global tested network is composed of around 40 PV inverters from different manufacturers.

## 2.1.2 Observation on the harmonic voltages

The rank 5$^{th}$ and 7$^{th}$ of the harmonic voltages are indicative of the power electronics quality. That is why threshold overrun for these two ranks has been examined particularly. The rms values of harmonic voltages averaged over 10 minutes must not exceed 6% for rank 5 and 5% for rank 7 (EN 50160 standard). The table below reflects the overruns for these harmonics from September 2012 to September 2013.

| N° | Event type | Date | Hour | Phase | Peak (V) | Duration |
|---|---|---|---|---|---|---|
| **5** | Harmonic [7] | 2013/04/14 | 15:50:00:16 | 3 | 12.01 | 10min |
| **6** | Harmonic [7] | 2013/04/14 | 15:20:00:14 | 3 | 11.66 | 10min |
| **8** | Harmonic [5] | 2013/06/09 | 18:10:00:18 | 2 | 14.17 | 50min |
| **14** | Harmonic [5] | 2013/06/09 | 07:40:00:15 | 2 | 14.17 | 40min |
| **15** | Harmonic [5] | 2013/06/09 | 06:40:00:10 | 2 | 14.09 | 40min |

| | | | | | | |
|---|---|---|---|---|---|---|
| **16** | Harmonic [5] | 2013/06/09 | 06:20:00:19 | 2 | 14.25 | 10min |
| **6** | Harmonic [5] | 2013/06/10 | 05:50:00:03 | 1 | 14.93 | 30min |
| **7** | Harmonic [5] | 2013/06/10 | 05:30:00:13 | 2 | 14.84 | 50min |
| **4** | Harmonic [5] | 2013/06/22 | 07:50:00:17 | 2 | 14 | 30min |
| **5** | Harmonic [5] | 2013/06/22 | 06:00:00:07 | 1 | 14.95 | 2h30min |
| **23** | Harmonic [5] | 2013/08/19 | 07:20:00:00 | 1 | 13.86 | 10min |
| **21** | Harmonic [5] | 2013/08/20 | 06:50:00:18 | 2 | 13.97 | 30min |
| **22** | Harmonic [5] | 2013/08/20 | 06:30:00:16 | 1 | 14.19 | 50min |
| **18** | Harmonic [5] | 2013/08/21 | 07:40:00:18 | 1 | 13.96 | 10min |
| **19** | Harmonic [5] | 2013/08/21 | 06:50:00:00 | 2 | 14.45 | 30min |
| **20** | Harmonic [5] | 2013/08/21 | 06:50:00:00 | 1 | 14.35 | 30min |
| **16** | Harmonic [5] | 2013/08/22 | 06:40:00:15 | 1 | 14.82 | 40min |
| **17** | Harmonic [5] | 2013/08/22 | 06:40:00:15 | 2 | 14.73 | 40min |
| **14** | Harmonic [5] | 2013/08/23 | 06:50:00:00 | 2 | 14.16 | 30min |
| **15** | Harmonic [5] | 2013/08/23 | 06:40:00:10 | 1 | 14.02 | 40min |
| **9** | Harmonic [5] | 2013/08/24 | 06:30:00:18 | 1 | 15.15 | 1h50min |
| **10** | Harmonic [5] | 2013/08/24 | 06:30:00:18 | 2 | 15.08 | 2h40min |
| **11** | Harmonic [5] | 2013/08/24 | 05:20:00:02 | 2 | 14.36 | 40min |
| **12** | Harmonic [5] | 2013/08/24 | 04:00:00:00 | 2 | 14.87 | 1h10min |
| **13** | Harmonic [5] | 2013/08/24 | 04:00:00:00 | 1 | 15.1 | 2h |

We can see that over a year, 10 days have slightly exceeded the voltage harmonic level for the 5$^{th}$ and 7$^{th}$ ranks.

### 2.1.3 Analysis

- ***5$^{th}$ rank harmonic***

The purpose of this analysis is to test whether such harmonic peaks are synchronous with high photovoltaic production.

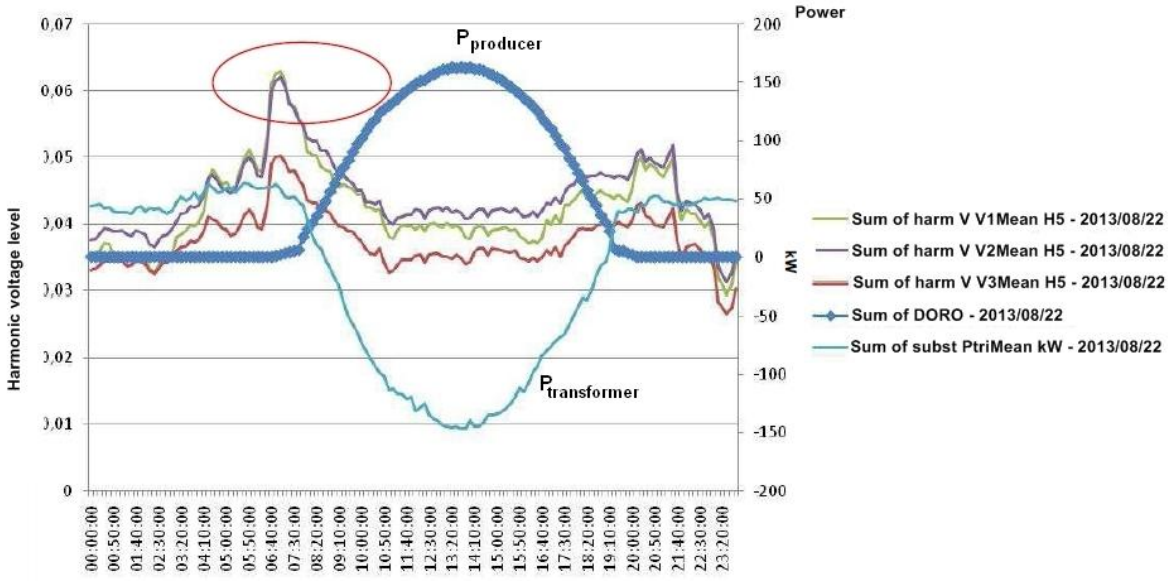



*Figure 2: Thursday 2013/08/22 measurements*

Figure 2 shows the production of one PV infrastructure connected to the substation (DORO: 190 kWp), the power drawn off at the distribution substation and the relative amplitude of 5$^{th}$ rank harmonic voltages (for the 3 phases). This business day shows a smooth PV generation, a cloudless day. We can assume that the production of other PV installations connected to this station is proportional to that producer. We can notice that between 7am and 8am, the relative amplitude exceeds the voltage limits set by EN 50160 standard. However, these overruns do not correspond to a PV inverters startup, as the facility begins to produce only around 8am, at low power. When PV inverters reach their maximum, relative amplitudes of harmonic voltages remain low. Indeed having an electrical production increases the short-circuit power. In the condition where production does not emit harmonic disturbances, it reduces the levels of H5 voltage harmonic. We can clearly see this phenomenon on the graph.

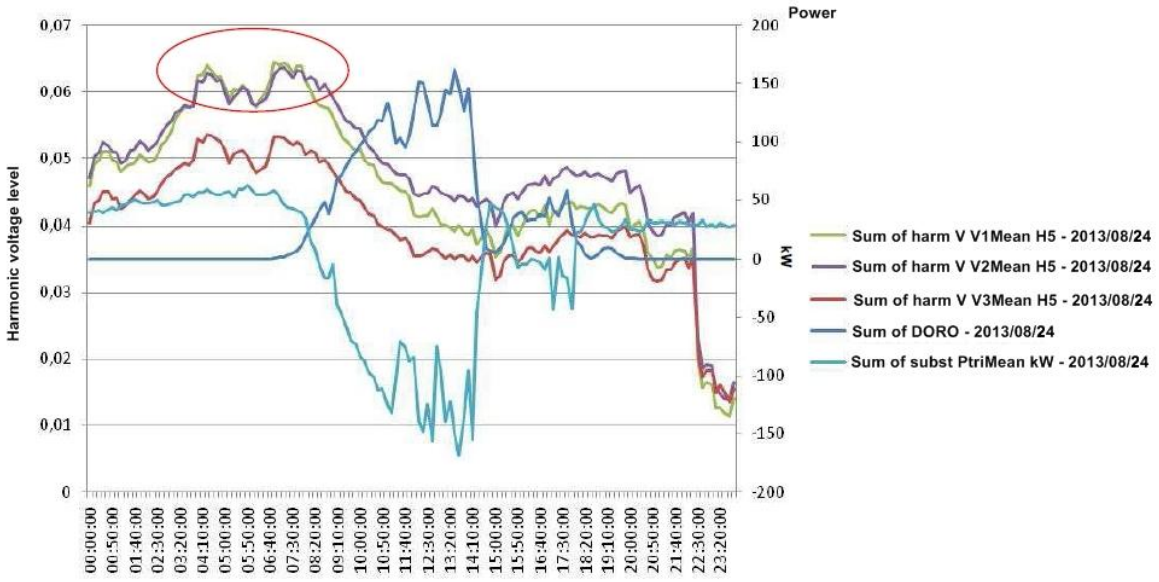

Power
Harmonic voltage level
kW
Sum of harm V V1Mean H5 - 2013/08/24
Sum of harm V V2Mean H5 - 2013/08/24
Sum of harm V V3Mean H5 - 2013/08/24
Sum of DORO - 2013/08/24
Sum of subst PtriMean kW - 2013/08/24

*Figure 3: Saturday 2013/08/24 measurements*

Figure 3 shows measurements for August 24, 2013, with a turbulent production. But as August 22, relative amplitude overruns of harmonic voltages are over the 6% limit well before the start of the PV production. Moreover, as before, the PV production increases the short-circuit power and limits H5 voltage harmonics.

To ensure that the measurement equipment clock has not offset from the production meters clocks, we have also analyzed measurement from the SMB / SMI (Small and Medium Businesses / Small and Medium Industries) meter installed at the Dock Trachel substation. As seen on Figure 4, the measurements from the SMB / SMI meter and the ones from the Alptec ($P_{TriMean}$) are completely synchronous.

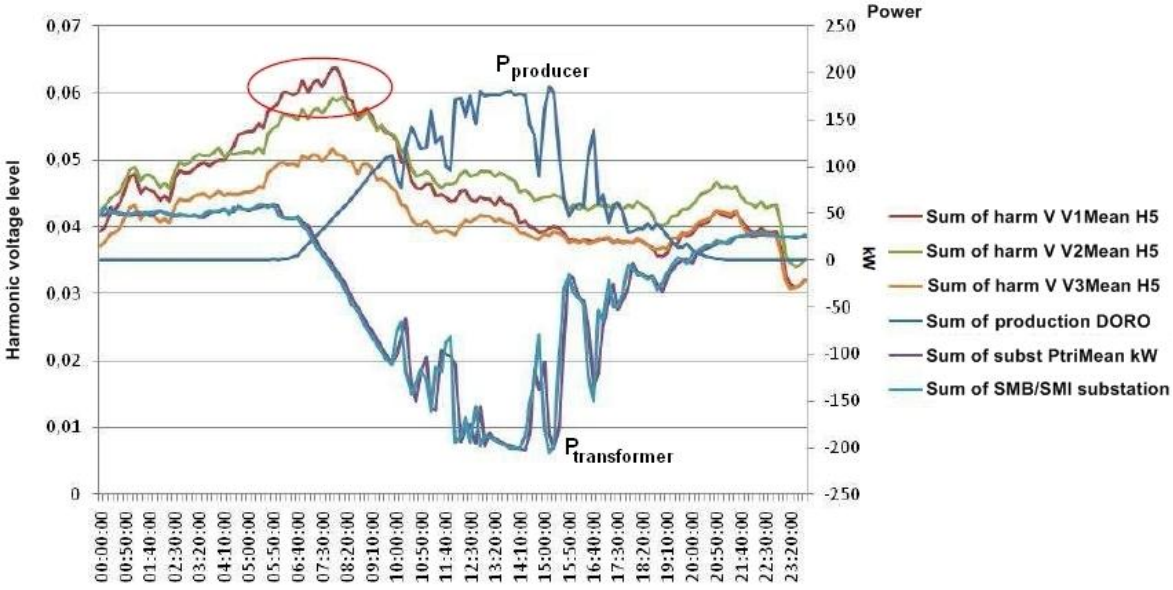



*Figure 4: Saturday 2013/06/22 measurements*

For all overruns of 5th rank harmonic voltages noted, this happened before the start of PV

production, except Sunday, June 9, with a very slight overrun negligible at 18:10, on a day when the production is very turbulent (see Figure 5).

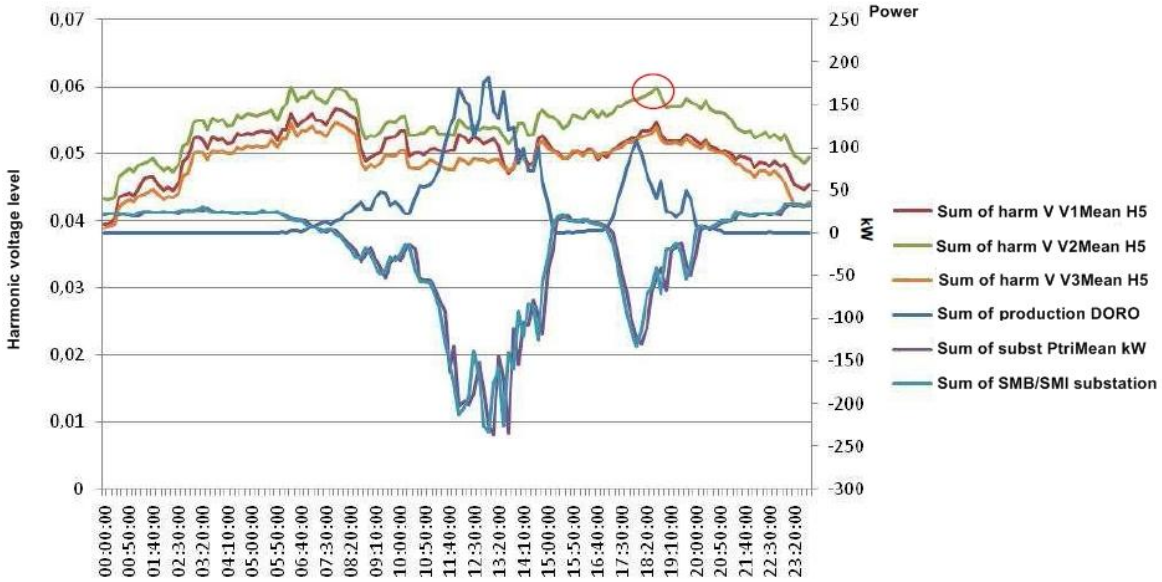

Harmonic voltage level
Power
kW
Sum of harm V V1Mean H5
Sum of harm V V2Mean H5
Sum of harm V V3Mean H5
Sum of production DORO
Sum of subst PtriMean kW
Sum of SMB/SMI substation

*Figure 5: Sunday 2013/06/09 measurements*

Moreover, these early morning overruns appear to be independent of the day of the week. Indeed, they have been observed on a Sunday, as well as a Monday or even a Thursday…

- ***7th rank harmonic***

Figure 6 shows an overrun of the relative amplitude of the 7th rank voltage harmonic (slight overrun of 5%). However this overrun between 3pm and 4pm is of very low significance. The reactive power presents a slight drop and at the same time H7 voltage harmonics levels drop as well (around 4pm). This could possibly be due to a harmonic resonance related to capacitor banks of reactive compensation. This assumption remains to be confirmed.

*Figure 6: Sunday 2013/04/14 measurements*

## 2.1.4 Influence of 140 kWp PV generator connection

A 140 kWp PV producer was connected to the Dock Trachel substation at 2013/11/07. The objective of this subchapter is to observe the 5th and 7th rank voltage harmonics between October and November to analyze if this connection has had an impact on these harmonics.

- ***5th rank harmonic***

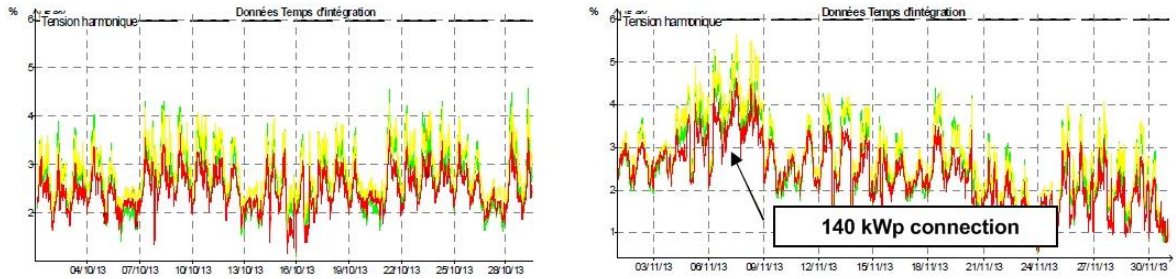



*Figure 7: H5 voltage harmonic (resolution: 10 min) - October and November*

| Curve | Average value | |
|---|---|---|
| | October | November |
| Nicegrid / V1 Moy H5 | 2,72 % | 2,6 % |
| Nicegrid / V2 Moy H5 | 2,92 % | 2,78 % |
| Nicegrid / V3 Moy H5 | 2,48 % | 2,37 % |

*Figure 8: H5 voltage harmonic average values - October and November*

We can see that the average values of H5 voltage harmonics for November are lower than the ones for October. We can just notice a slight increase of these values on November 6, 7 and 8, but then to drop back to same values than October.

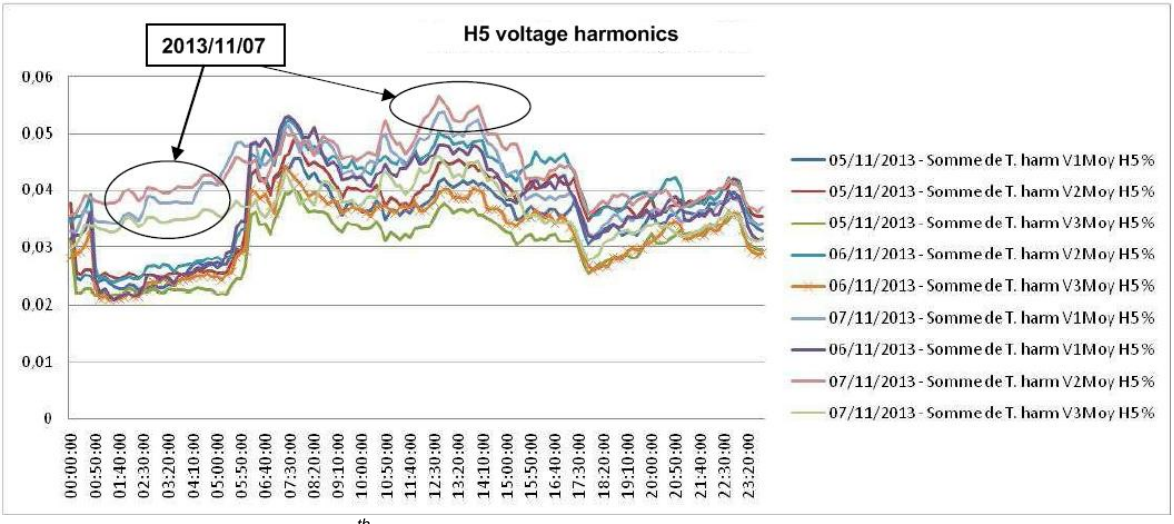

H5 voltage harmonics
2013/11/07
0,06
0,05
0,04
0,03
0,02
0,01
0
05/11/2013 - Somme de T. harm V1Moy H5 %
05/11/2013 - Somme de T. harm V2Moy H5 %
05/11/2013 - Somme de T. harm V3Moy H5 %
06/11/2013 - Somme de T. harm V2Moy H5 %
06/11/2013 - Somme de T. harm V3Moy H5 %
07/11/2013 - Somme de T. harm V1Moy H5 %
06/11/2013 - Somme de T. harm V1Moy H5 %
07/11/2013 - Somme de T. harm V2Moy H5 %
07/11/2013 - Somme de T. harm V3Moy H5 %

*Figure 9: 5th rank voltage harmonics November 2013, 5, 6 and 7*

In Figure 10, we can notice that the commissioning of the 140 kWp producer did not result in significant changes in the consumption of the substation. The production of November 7 seems higher than the one of November 5 and 6 (in view of consumption values), but remains below the production of a few days at the beginning and middle of the month.

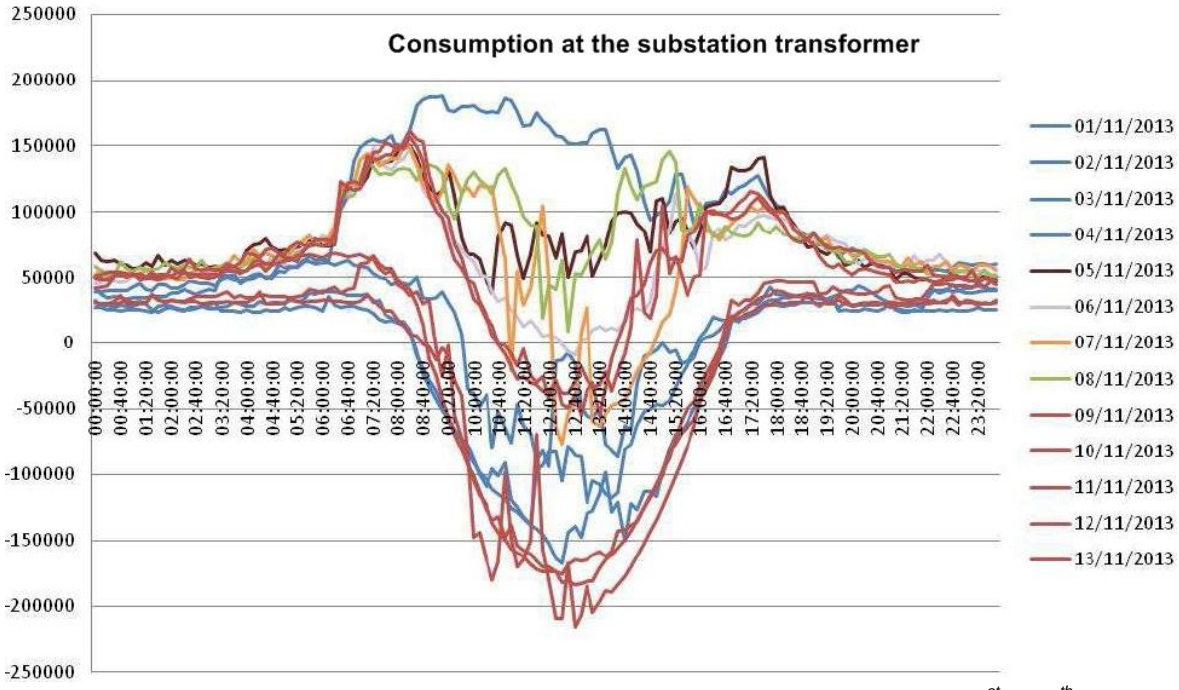



*Figure 10: Consumption at the Dock Trachel substation (W) November 2013 from 1st to 13th*

So 5th rank voltage harmonics decrease during the month without matching, a priori, a strong PV production, we cannot conclusively determine the cause of this increase in these voltage harmonics of November 7 and 8.

- ***7th rank harmonic***

As for 5th rank, the average values of voltage harmonics are lower in November than in October. We do not see a sudden rise on November 7.

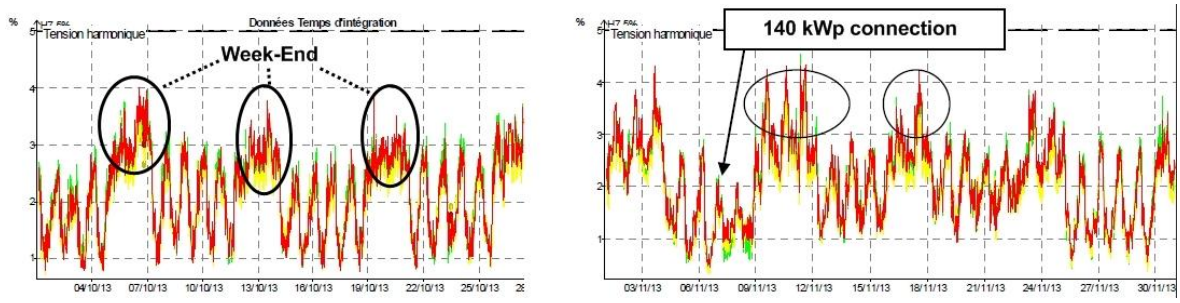



*Figure 11: H7 voltage harmonic (resolution: 10min) - October and November*

| Curve | Average value | |
|---|---|---|
| | October | November |
| Nicegrid / V1 Moy H5 | 2,19 % | 2,1 % |
| Nicegrid / V2 Moy H5 | 2,07 % | 1,98 % |
| Nicegrid / V3 Moy H5 | 2,17 % | 2,14 % |

*Figure 12: H7 voltage harmonic average values - October and November*

However, we can notice that on November 9-10-11 and 16-17, the values of 7th rank voltage harmonic seem a bit higher (Figure 13).

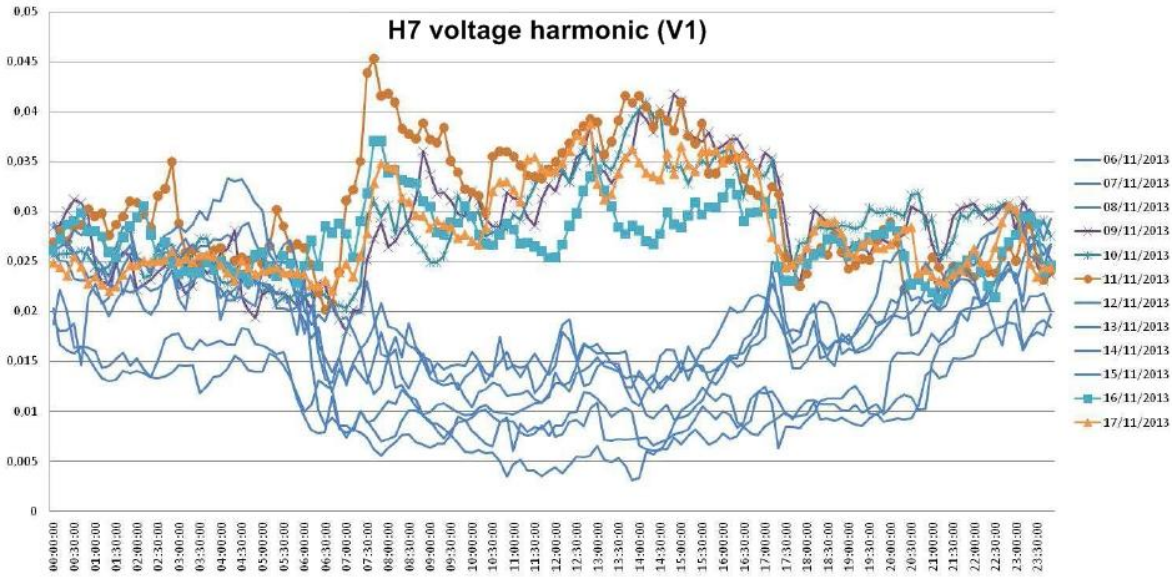



*Figure 13: H7 voltage harmonic (V1) November 2013 from 6th to 17th*

When we have a look at the load curve at the substation (
Figure 14), we can see that these days correspond to lower consumptions (and a priori larger productions).

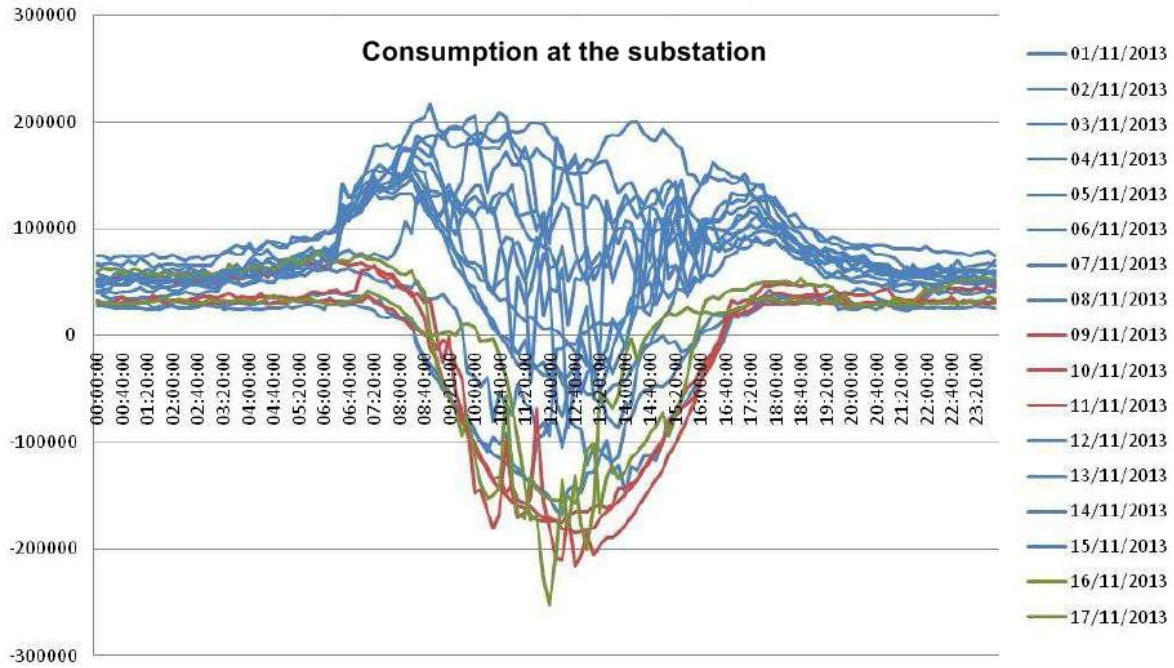



*Figure 14: Consumption at the Dock Trachel substation (W) November 2013 from 1st to 17th (highlighting 9-10-11 and 16-17)*

### 2.1.5 Results

All overruns of 5th rank voltage harmonics level appear before the start of PV production (between 4am and 7:50am at the latest). Increases of the voltage harmonics level do not appear to be temporally correlated with PV generation contrarily to the drops of voltage harmonics levels. Indeed, the PV production increases the short-circuit power without emitting harmonic disturbances, it allows reducing the H5 voltage harmonics.

Currently, it is not possible to know the cause of threshold overruns. Future instrumentation of all feeders will allow knowing if the overruns come from a single feeder, and therefore a specific consumer.

After the connection of a new 140 kWp generator on the Dock Trachel substation, average values of 5th and 7th ranks voltage harmonics are lower on November than on October. There is a slight increase in 5th rank voltage harmonics between November 6th and 7th, but since these levels decrease for the rest of the month and do not correspond to an increase in production, we cannot conclude on the origin of this low increase. On the other hand, we can see a very slight increase of 7th rank voltage harmonics on days where consumption is more negative (a fortiori higher production).

These data do not support the hypothesis that connecting a 140 kWp PV producer impacts the harmonic levels but encourages us to monitor these phenomena, with more data (including production data and data for each feeder) and on sunny summer days.

## 2.2 Measuring devices installed and decentralized PV

### 2.2.1 Introduction

ERDF is responsible for the quality and the continuity of the electricity supply in France. Thanks to its management of the low and medium voltage networks, the quality of supply in France is one of the best in Europe. Still, the company has to keep investing and innovating namely in order to adapt the network to the ever increasing penetration rate of renewable production on the distribution level.

Several indicators have been implemented to assess and improve the quality of the electricity supply. The 'Critère B' is one of the best examples, it was created to curb the average outage time. But outage time is not the only indicator of a good quality of supply, voltage is also very important as recurring and large increases or decreases in voltage can damage appliances. That is why the voltage delivered to the end consumer has to be kept within an acceptable range. This range was set to 230 +/- 10% via a European and French decree.

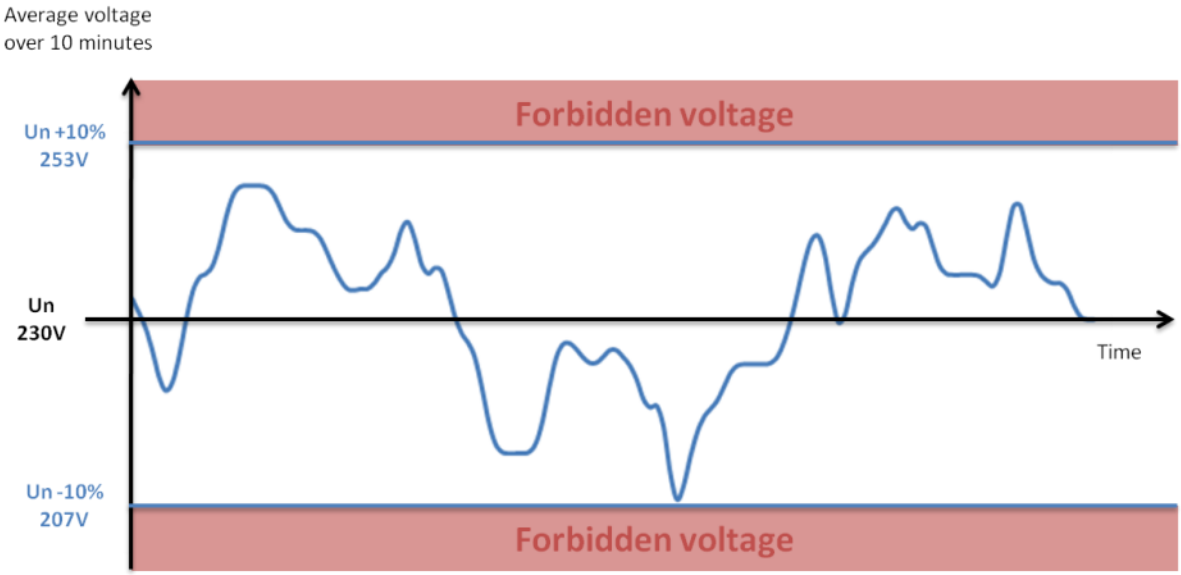



*Figure 15 - Voltage range*

It is important to keep in mind that this range refers to an average of the voltage over ten minutes. This means that the voltage can actually increase to more than 230 +10% for a few seconds (even minutes) as long as the 10-minute average remains lower.

The constraints regarding the quality of electricity supply have been set so that consumers have access to a reliable source of electricity that will not damage their equipments, but these are not the only constraints that ERDF has to deal with. Indeed, ERDF must also ensure that the network is operated within the constraints of its different components. These constraints usually translate in a maximum amount of electricity that can transit through each element, such as lines and transformers, and breaching those constraints eventually results in damages to said equipments.

To manage the grid and ensure the respect of the different constraints, ERDF needs to carefully monitor the grid. In this deliverable, we look at the different measuring devices used in NICE GRID and then use them to assess the evolution of the voltage on the grid in the project and to analyse the efficiency of the voltage control methods tested in the project.

### 2.2.2 Potential impact of customer engagement on the voltage

- **Voltage and load curve**

Historically, the French network was built to transport the electricity from a few large producers to a great number of consumers. This led to the creation of a distribution network designed to supply electricity to the consumers connected to the medium or low voltage networks. Thus, as every consumption of electricity leads to a decrease in the voltage, one of the main issues when building the distribution network was to ensure that the voltage did not drop under 230V -10%. Indeed the only increases in voltage between phase and neutral were due to the network phases being unbalanced, and they were rare.

This paradigm is now changing as the penetration rate of the production on the distribution network is increasing, namely thanks to PV production. When the penetration rate is high enough, production can at certain times overcome consumption on a low voltage feeder leading to an increase in voltage rather than a decrease. As the network was not designed with this possibility in mind, the 230V +10% threshold can sometimes be breached – this is even more likely in areas where the balance of the phases has not been respected.

The fact that most of the production connected to the low voltage network is PV makes this even more likely. Indeed, PV production tends to be installed in residential areas where the demand is quite low when the PV production is maximal (midday).

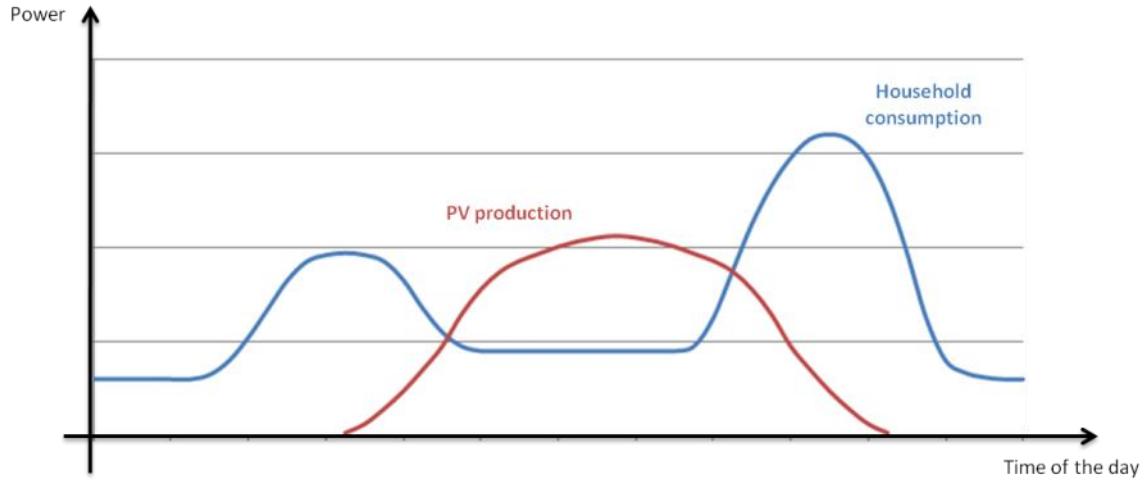



*Figure 16 - Consumption and production curve*

The importance of the residential areas when it comes to the integration of PV production is reflected in the NICE GRID project by the presence of six residential areas among the seven solar

districts [1]of the project. In each of these solar districts, the project is experimenting innovative ways of matching the solar production curve with the demand curve in order to mitigate the risk of overvoltages. While new technologies are necessary to the integration of PV production, the project lays the emphasis on the importance of engaging the customer in the process.

- **Engaging the customer**

Engaging the customers and having them participate in the experiments is one of the main objectives of the NICE GRID project. Indeed, while technologies such as batteries can be used to move part of the production to the peak consumption period, engaged customers can move some of their consumption to the production period without requiring complex devices such as batteries.

Moving consumption so that the load better matches the production on the low voltage network is an efficient way of mitigating the risk of an increase in voltage. Indeed, it can prevent the production from overcoming the demand. This highlights the tight links that exist between local load curves and local voltage variations as well as the importance of the social dimension of the project for its scientific results.

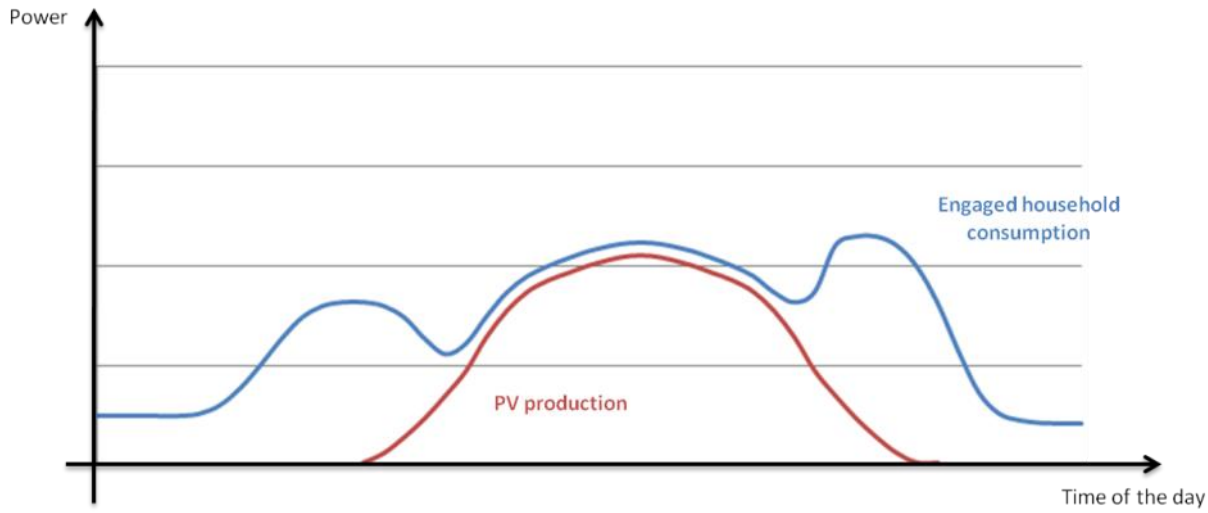



*Figure 17 - Consumption and production curve adjusted*

To engage the customers who live in areas where PV production could be a problem, the project has put in place several experiments that all rely on the idea of 'solar off-peak periods'. Every summer, forty days are selected as 'solar days' and on these days, the customers taking part in the project benefit from four additional off-peak hours between 12pm and 4pm. Depending on the customer's level of involvement in the project, these hours are used differently:

- Some customers will only be urged to increase their consumption during that time (thanks to the lower prices);

[1] A solar district is a secondary substation and its corresponding customers.

- Some customers will have their electric water heater turned on remotely;
- Customers with PV production and a residential battery will have their battery charging.

### 2.2.3 Usage of the LINKY smart meter

- **What is LINKY?**

The LINKY smart meter is a communicating meter that is going to be rolled out in France. These smart meters will provide much more details regarding the consumption and the quality of electricity than the current meters (such as the consumption at a 10-minute step or the voltage). They will also be operable remotely thus reducing the need for onsite interventions and the delay for maintenance.

The communication between each meter and the information system that centralises the data is divided into two main steps. First, the meter sends the information to a concentrator localised in the secondary substation using Power Line Carrier (PLC) communication. Then, the concentrator communicates with the supervision centre through GPRS. The electricity suppliers will then have access to some of the data that relate to their customers.

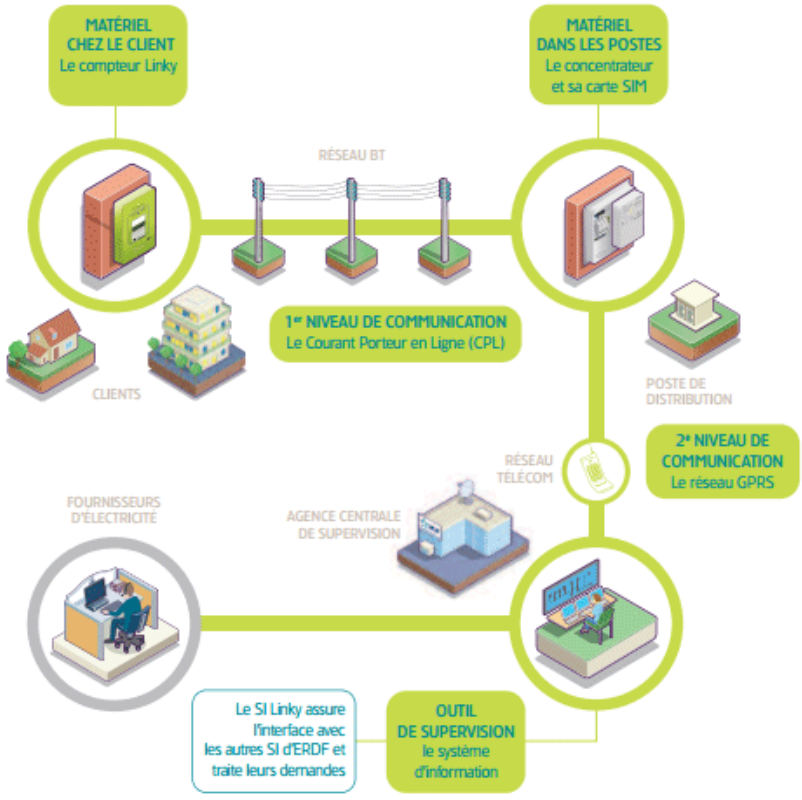

MATÉRIEL CHEZ LE CLIENT
Le compteur Linky
MATÉRIEL DANS LES POSTES
Le concentrateur et sa carte SIM
RÉSEAU BT
1er NIVEAU DE COMMUNICATION
Le Courant Porteur en Ligne (CPL)
CLIENTS
POSTE DE DISTRIBUTION
2e NIVEAU DE COMMUNICATION
Le réseau GPRS
RÉSEAU TÉLÉCOM
FOURNISSEURS D'ÉLECTRICITÉ
AGENCE CENTRALE DE SUPERVISION
Le SI Linky assure l'interface avec les autres SI d'ERDF et traite leurs demandes
OUTIL DE SUPERVISION le système d'information

*Figure 18 - linky infrastructure*

All the consumption data are encrypted at the meter level as ERDF has to ensure the privacy of the customer's data. The permanent connection of the meter to the information system and its capacity to measure multiple variables regarding electricity will allow for:

- A calculation of the bills based on real rather than estimated consumptions;
- Next-day interventions for simple tasks such as the modification of the contracted power instead of the current five days delay, thanks to remote access;
- A better knowledge and control of their electricity consumption by customers as they will be able to visualise it on their electronic devices (computer, smart phones, tablets...)
- Easier diagnostics of the problems in case of a power outage thus a reduction of the Critère B (average yearly outage time per customer).

These are some of the most advertised advantages of rolling out the LINKY meter, but there are others. Indeed, it is important to highlight the fact that it is difficult to gather information regarding the real time state of the distribution grid today. LINKY meters will provide ERDF with a constant stream of data that will prove useful when it comes to managing the grid.

In the case of the NICE GRID project, one of the most valuable measures is the voltage.

The roll out of LINKY meters in Carros started in June 2012 and two years later, there are now over 1800 meters installed. The meters were installed in selected districts that correspond to the seven solar districts of the project as well as some neighbourhoods with a high penetration of electric heating. These meters now provide the project with data streams that consist in 10-minute points – which is consistent with the decree that deals with 10-minute averages. However, these data points are only retrieved to the server on a daily basis.

- **Voltage measurements at +/- 10%**

By default, voltage is only measured when it is out of the 230V +/- 10% range. This is a way of saving on storage space. This means that the resulting curves are 'holey' as no data is recorded as long as the voltage is within the +/- 10% range. Such a figure can be found below.

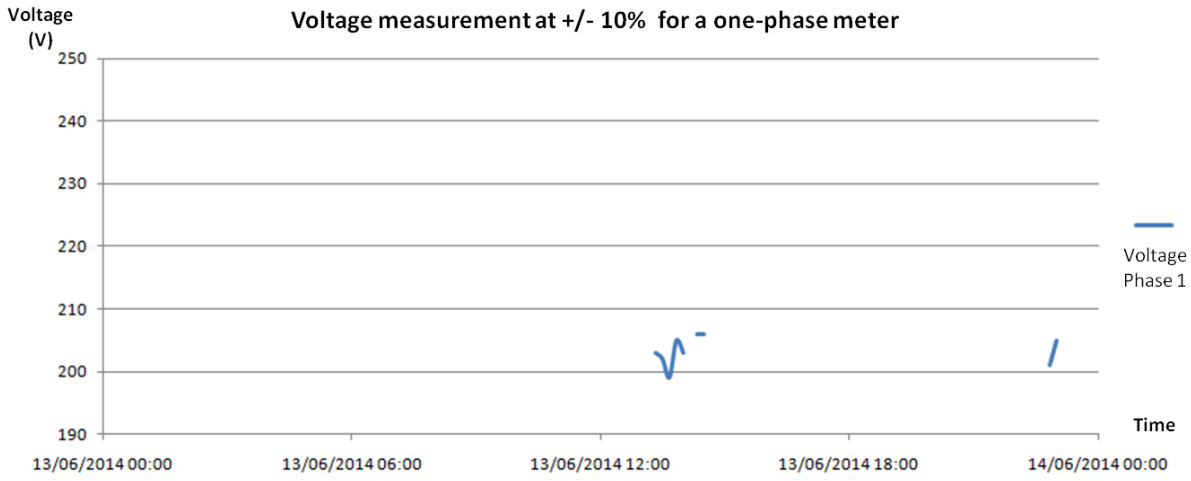



*Figure 19 - Voltage measurement at +/- 10% for a one phase meter*

If the meter is three-phased, then it will log the voltage of the three phases every time one of the phases is out of the acceptable range.

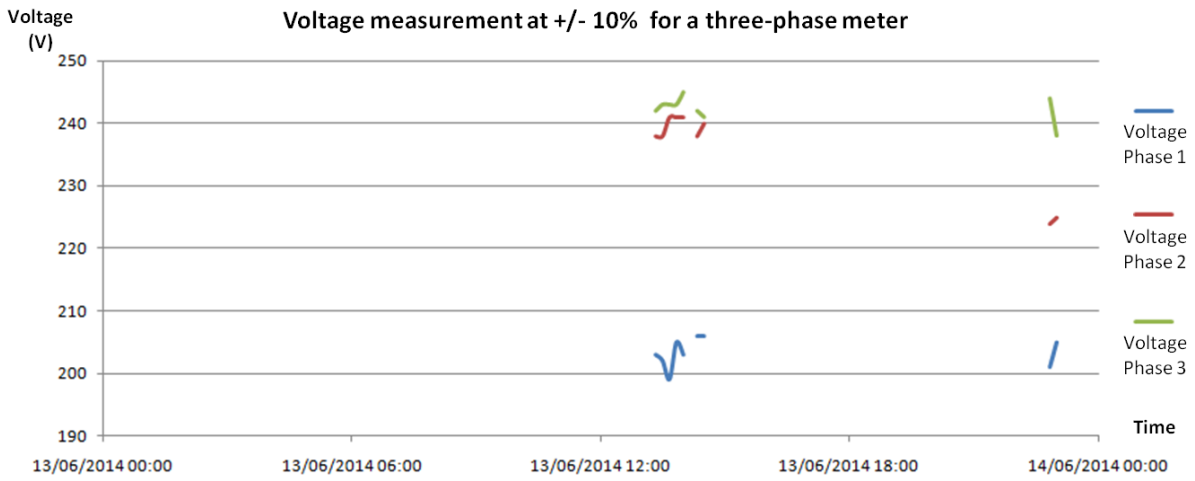
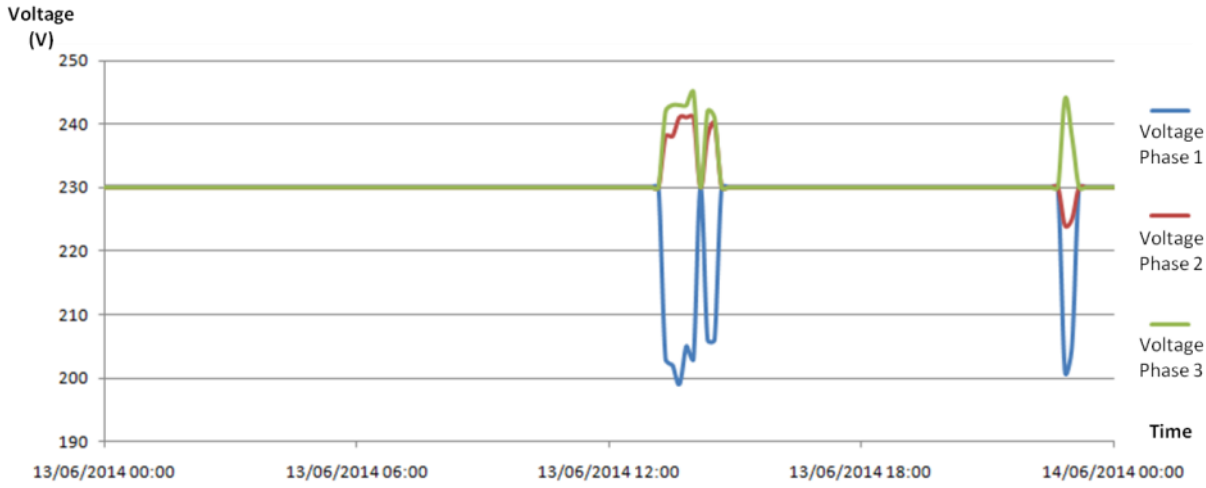



*Figure 20 - Voltage measurement for a three phase meter*

To improve readability, the holes are replaced by a 230V voltage in the next figure. It is however important to keep in mind that this does not reflect the true evolution of voltage. This is why this approximation has never been used subsequently.




Recording only the values out of the +/- 10% range to save on the data storage costs makes sense when rolling out the meters across the whole country as these are the only important values from a regulation perspective. However, in a project such as NICE GRID that aims to assess the impact of PV production and mitigation measures on the voltage, more information is required. Indeed, the 10% threshold prevents us from seeing most of the variations during the day and makes any accurate analysis impossible. All we can conclude is that increases or decreases in voltage on a phase tend to be balanced by the other phases; this can lead to surprising situations such as high voltage in the evening when consumption is at a maximum and PV production at a minimum.

- **How to get a better assessment of the voltage variations with the LINKY meter**

So as to obtain more accurate measurements and a clearer picture of the evolution of voltage during the day, a few key meters were modified to record all voltage values. Indeed, LINKY meters can be used as real voltage meters and record the average voltage every 10 minutes on one phase or on the three phases depending on type of meter. In order not to use too much storage space, each low-voltage feeder that was monitored had up to three meters with a full voltage measurement. As the project's objective is to mitigate increases in voltage on the network, the modified meters were selected so that they would provide us with an overview of the voltage over the entire length of their feeder – meaning that measurements had to be taken close to the substation, in the middle of the network and at the end of the line.

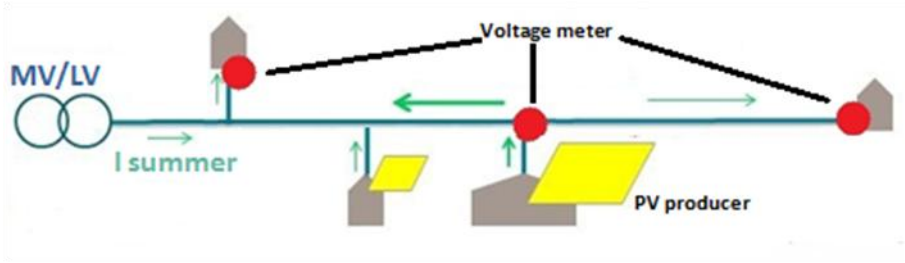



*Figure 21 - Voltage measurement*

Priority was given first to three-phased meters as they give simultaneously the phase-neutral voltage on the three phases, thus providing a better overview of the network. However, when no three-phased meter was available at an interesting location, the project settled for the modification of three one-phased meters connected to different phases and located close from one another.

The localisations of these sample meters in the seven secondary substation that take part in the 'mitigating the increase in voltage due to PV production' experiment are detailed next.

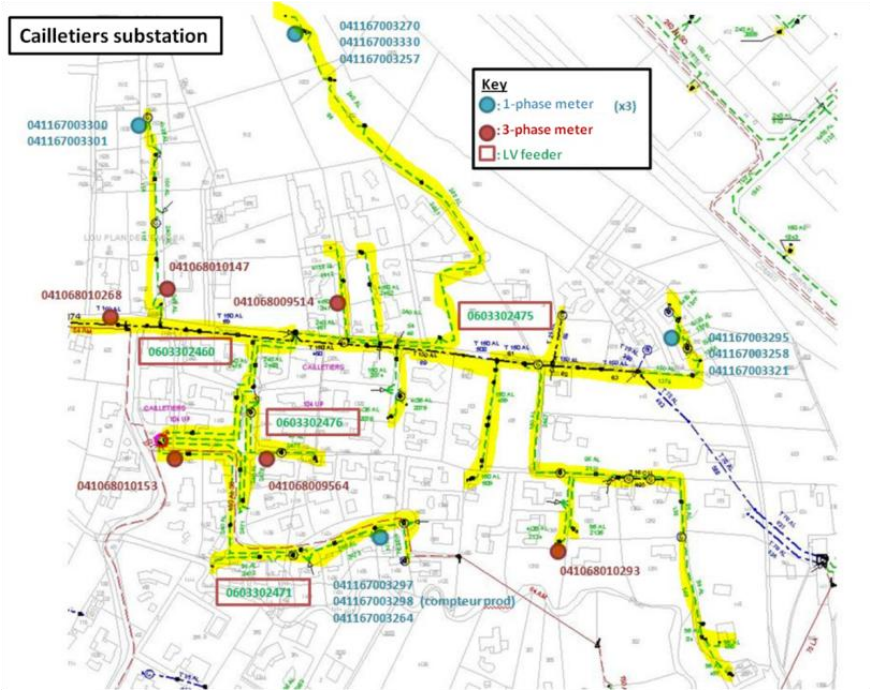



*Figure 22 - Cailletiers substation*

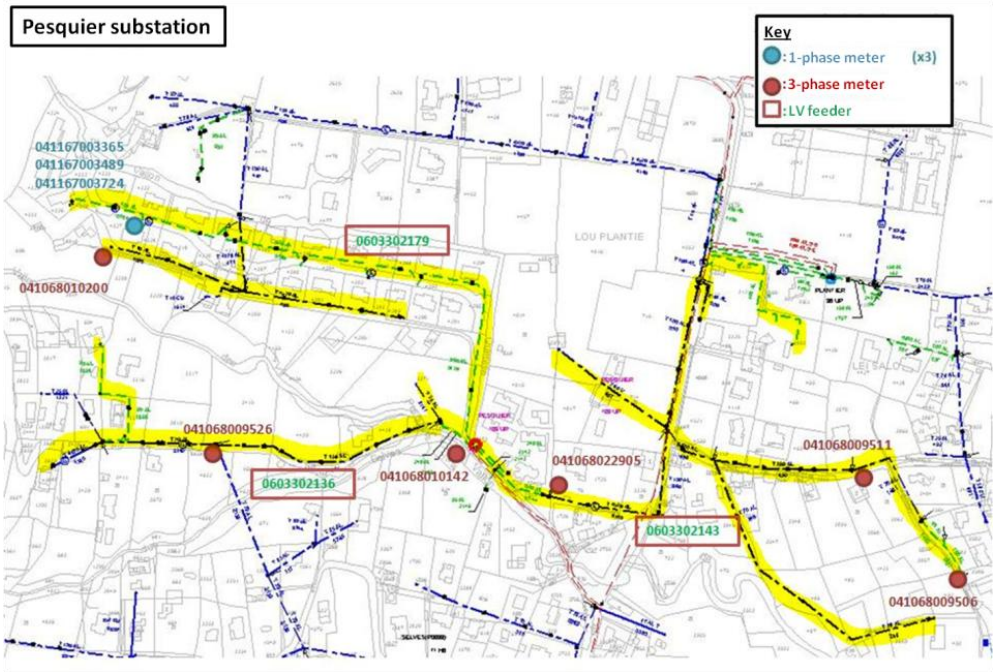



*Figure 23 - Pesquier substation*

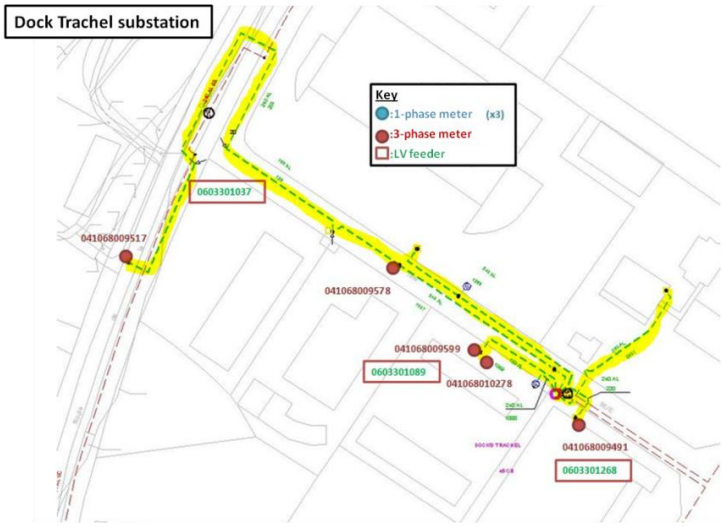



*Figure 24 - Dock trachel substation*

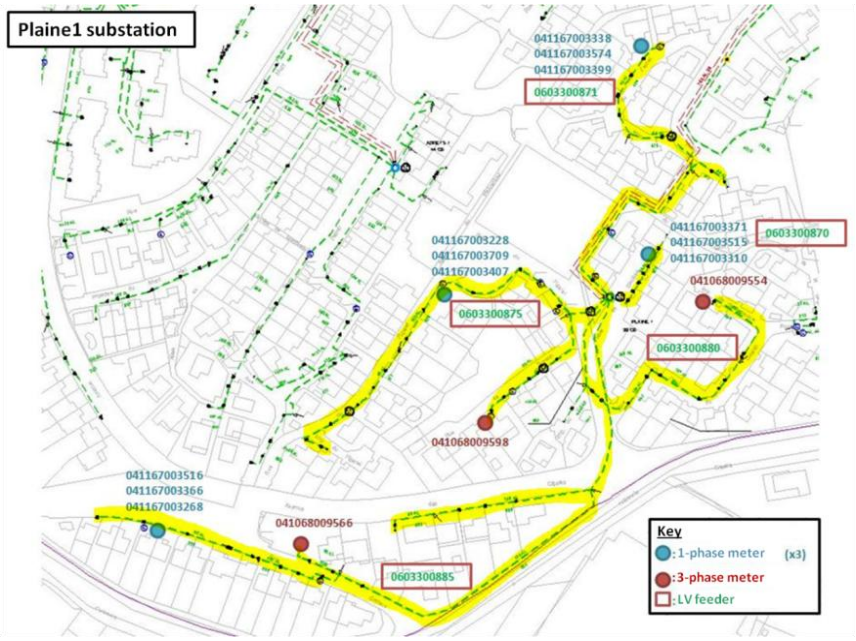



*Figure 26 - Plaine 1 substation*

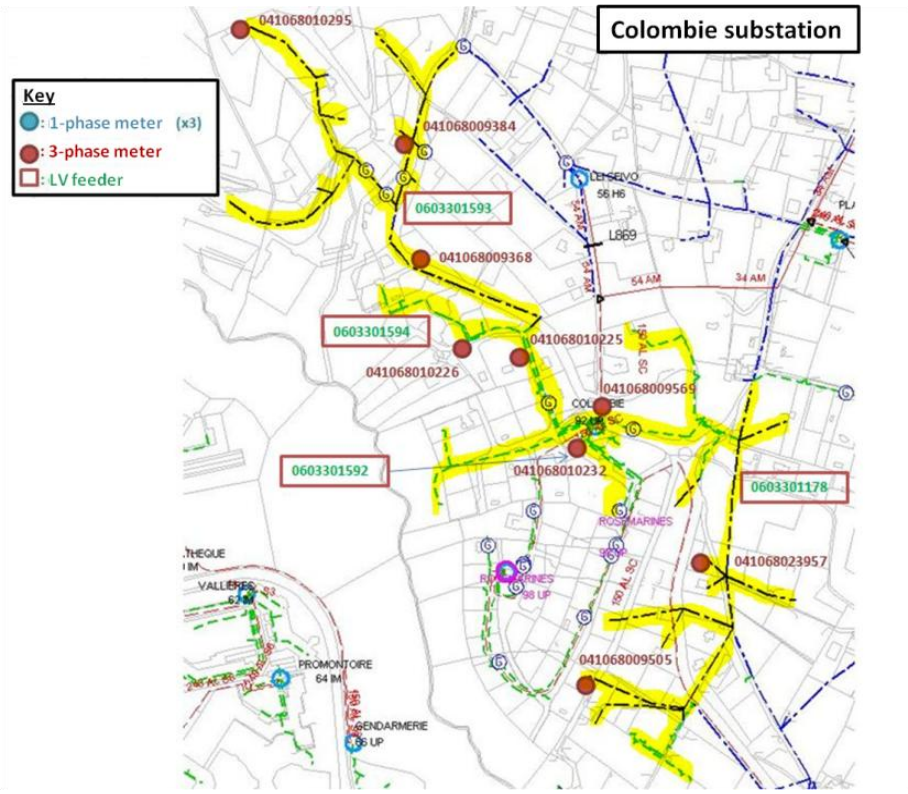



*Figure 25 - Colombie substation*

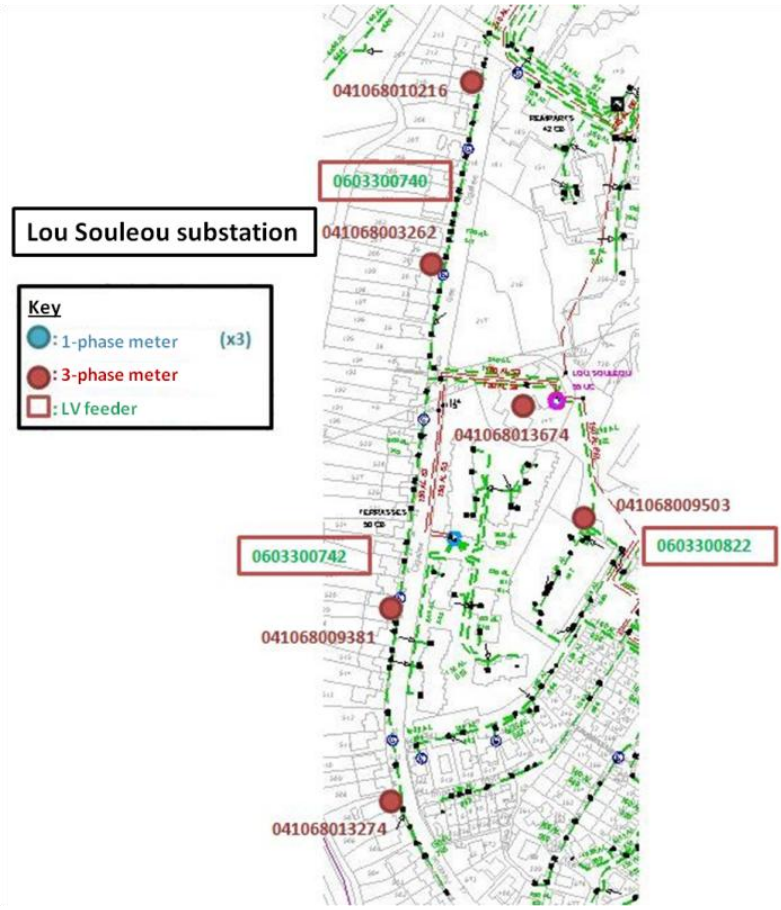



*Figure 27 - Lou Souleou substation*

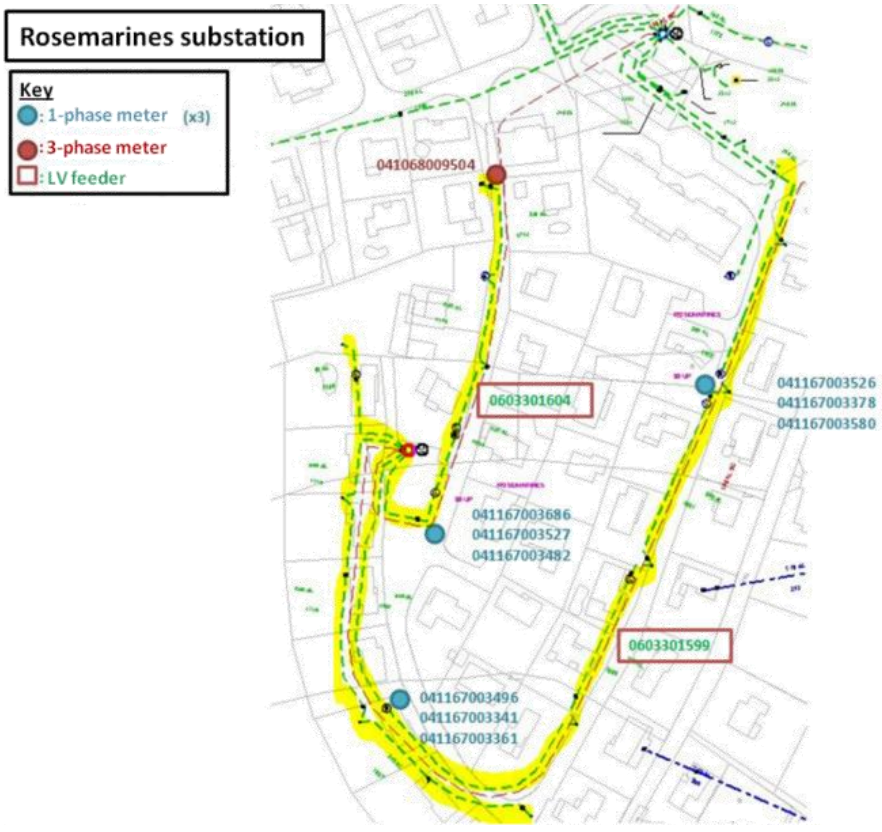
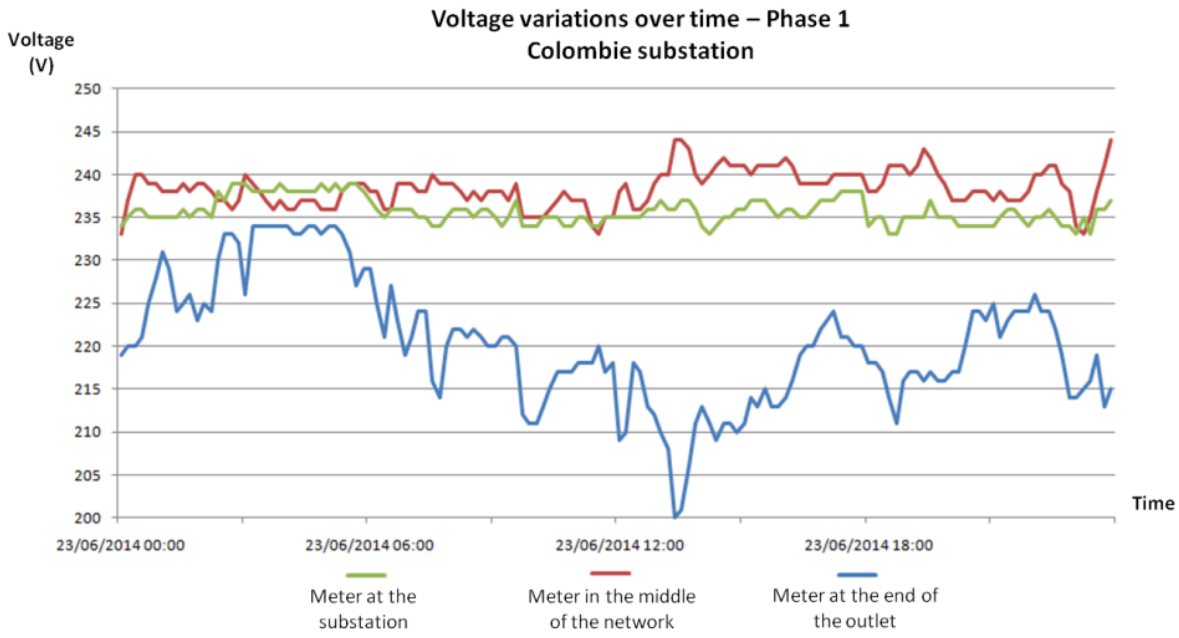



*Figure 28 - Rosemarines substation*

These selected meters give us a more accurate overview of the evolution of voltage over time and make it possible for us to analyse the way the voltage varies throughout the network over time. For example, the figure below displays the evolution of voltage on Phase 1 over a week day at the three sample meters of one of Colombie substation's feeder (0603301593).

This feeder has one of the highest penetrations of PV production in the project (10%), making it one of the most likely to display increases in voltage. The meter situated the closest to the substation provides us with data showing that the voltage at the substation is not constant during the whole day; variations on the MV level affect it. It must be noted that the MV variations are smaller than average in Carros as the MV feeders are short and strong.

The variations of the two meters situated further downstream appear much more difficult to analyse with a very large gap between the mid- and end- network voltage. Deeper analysis is required to unscramble these data, it is carried out in Appendix I. It must however already be highlighted that the voltage variations on this feeder should not be regarded as standard. This feeder is very long and its phases are unbalanced, the combination of these factors leads to voltage variations that are much more important than those of typical feeders.




- **Assessing the involvement of engaged customers**

The LINKY meters were also used to assess the involvement of the customers participating in the project. Indeed, it is essential to know how much load can be shifted to the production period by engaged customers as this will determine the number of engaged customers necessary to mitigate the risks posed by PV production on low voltage networks.

The analysis of the power data during the beginning of the 2014 summer experiment is carried out in Appendix II and provides us with some feedback on that subject. The general result is that engaged customers with an electric water heater triggered remotely by the project will see a massive change in their consumption pattern on a 'solar day' as their consumption will peak for about one hour during the afternoon. The effect of this change in behaviour on the voltage of the local grid remains to be confirmed but still, this first result tend to indicate that electric water heaters could be used to compensate the PV production on the condition that several water heaters are triggered successively.

### 2.2.4 Usage of the PME-PMI meters

- **Complementing the LINKY data**

As seen in the previous section, the LINKY meters are the cornerstone of the Smart Grid infrastructure in France as they provide the network operator with the information necessary to the future day-to-day monitoring and management of the low voltage networks. This information includes the demand, the production and the voltage. However, even though the LINKY meters are to play a major role in the monitoring of the low voltage network, Smart Grid projects often complete them with additional meters situated in critical positions – the NICE GRID project opted for PME-PMI meters.

The PME-PMI meters are traditionally used as equivalent to LINKY meters for customers contracting a power superior to 36 kVA. In NICE GRID, these meters are indeed used for large customers but eight additional meters have also been included and are used to monitor each of the seven substations corresponding to the 'solar districts', as well as one of the main PV producers.

- **Role of the PME-PMI meters located in the substations**

The first function of these meters is to offer a quick and simple way of checking the LINKY data regarding demand and production. Indeed, the aggregation of the loads recorded by the LINKY meters downstream of each PME-PMI meter should be roughly similar to the load recorded by the PME-PMI meter (however, it will not be identical as only about 90% of the customers are equipped with LINKY meters).

The second function is to provide the network operator with a practical solution for the real time monitoring and management of the network.

Having only a few meters makes it possible to retrieve the data as often as it is measured, while the LINKY data suffers from a gap between the frequency of measuring (every ten minutes) and the frequency of retrieval (every day) that is due to the large number of LINKY meters.

Retrieving some aggregated data every ten minutes is necessary to the real time management of the network as a daily retrieval is only good enough for billings, post-event analysis and predictions regarding the next day. Thus, fitting PME-PMI meters in the most interesting secondary substations is a good way of gaining global information that can be collected more easily and used closer to real time.

For instance, there are about 630 LINKY meters in the seven solar districts of NICE GRID. They represent a quantity of data that is much more difficult to retrieve and process in real time than the seven PME-PMI meters needed to fit the solar substations.

If we combine the two functions, we see that the project could in a future experiment re-evaluate the consumption predictions on the day by comparing the PME-PMI data of the morning with what was predicted.

- **Role of the PME-PMI meter equipping a solar producer**

This meter is used to quickly assess the level of PV production of the seven solar districts. Indeed, the project calculated in 2013 the ratio between the production of each district and the production of this installation. For instance, all the PV producers downstream of the Cailletiers substation represent about 12% of this main producer.

This approximation is made possible by the fact that Carros is a relatively small city and that we measure the average production over 10 minute. Both these factors combined lead to the conclusion that any change in weather can be considered as affecting simultaneously all the different producers.

Eventually, this meter and its 10-minute step data will allow the project to recalibrate its production predictions on the day by simply checking whether the sun is shining as much as predicted.

- **General use of the PME-PMI meters and retrieval of the data**

In addition to their value when it comes to predictions, PME-PMI meters can also be used to have a more complete overview of each solar district. Indeed, despite the project's best efforts, only around 90% of the customers within the seven solar districts are equipped with LINKY meters. One of the main reasons is that some of the customers were not in situations that allowed for the installation of a smart meter, for instance some were on a tariff that was not compatible with the version of LINKY rolled out in the project. Moreover, the change of the ancient meter to the LINKY meter was encourage but no compulsory, as this is only a demonstration project.

On a general note, the data collected by the PME-PMI meters will be used within Alstom's solar console to provide the user with a quick visualisation of the load in each solar district and of the PV production of the area. It may eventually enable the development of advanced micro grid functions.

On a more technical subject, the retrieval of the data makes use of several technologies. Data points are transmitted every ten minutes to the project's server by a WebdynTIC. A WebdynTIC is a communicating platform that periodically retrieves the data from the meters and uploads it to a server chosen by the user. The data streams are communicated by Broadband PowerLine (BPL), a fast PLC technology compatible with MV networks, to the primary substation where a broadband internet connection to the ERDF network retrieves them to the server. An additional retrieval takes place on a daily basis through a GSM channel.

### 2.2.5 Usage of the ALPTEC measuring devices

- **Requirements for additional measures**

The previous sections tackled the subject of the LINKY and PME-PMI meters that provide the network operator with data regarding the power and the voltage variations.

These data are critical when it comes to maintaining the voltage within the 230 V +/-10% range, especially if the penetration of PV production is high. However, the assessment of power quality is not limited to them and parameters such as harmonics, rapid voltage spikes and flicker also need to be monitored.

Indeed, even though it is true that the network will need to be better monitored and controlled to mitigate the increases in voltage that can be created by decentralised production, these increases are not the only type of problems that can affect low voltage networks in the future. New usages such as electric vehicles, decentralised production or the management of flexible loads require the use of power electronics that can have a massive impact on power quality. On top of the variations of voltage monitored with LINKY, it is thus necessary to assess the level of harmonics, the flicker and the rapid variations of voltage. To monitor and analyse these phenomena, 10-minute step recordings are not enough and additional devices have to be installed to log data on a second-by-second basis.

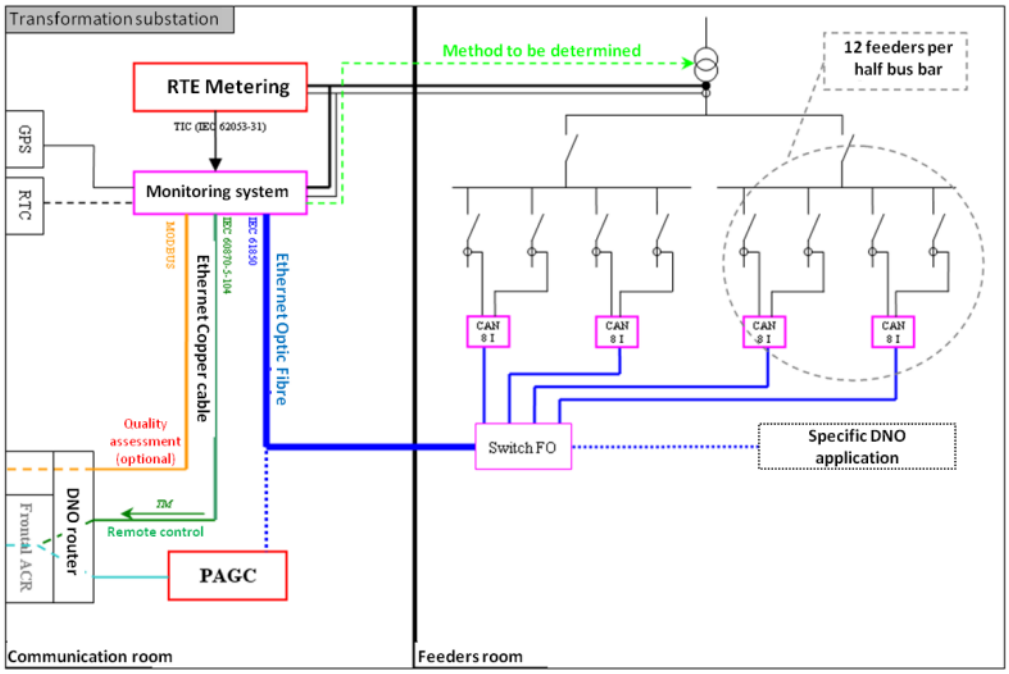
The project needed to install such devices in order to complete its assessment of the network behaviour when the penetration of PV production is high. The next section will detail these additional equipments, especially the one fitted on the feeders of the 'Dock Trachel' secondary substation as this is the substation with the largest consumers and producers (including a 200 kWp PV producer).

- **Measuring devices**

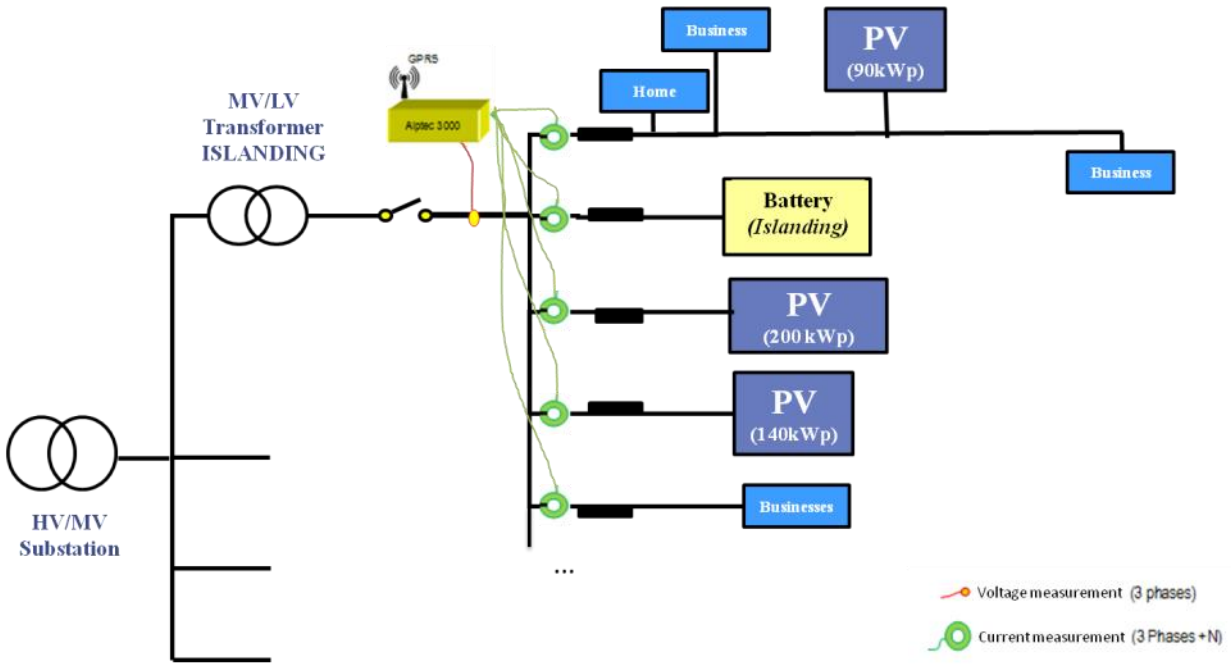
Measuring devices such as the ones required by the project are used industrially in primary substations as the monitoring at that level is already quite thorough. Installing such devices in secondary substations is thus quite similar to the matter of the solar transformer (an OLTC transformer installed in a secondary substation) as it corresponds to moving some advanced functions further downstream to gain in accuracy and in flexibility.

ALPES TECHNOLOGY has developed a range of measuring devices that respond to the project's requirements. These products are called ALPTEC and each one of them is capable of monitoring all the transformers and feeders (over the three phases) of a substation thanks to a set of modular sensors (SmartCAN).

After two years with a simpler ALPTEC that will be presented later on, the 'Dock Trachel' substation has been fitted with an ALPTEC-3000 since mid-July 2014. This monitoring system can provide measures allowing the assessment of power quality (CEI 61000-4-30 standard) as well as the remote operation of the network (IEC 60870-5-104 and IEC 61850). The ALPTEC-3000 monitors all the electrical parameters (including power quality) on every feeder of the 'Dock Trachel' substation and takes a series of measurements every 3 seconds. The figures below display how it is installed in the substation to monitor the different feeders.




- Synchronised system via Ethernet (IEEE1588)
- Sampled signal (200 kHz)and generation of two streams of samples:
  - ALPTEC-3000 :
    - 10 kHz set
    - 10 kHz PLL
  - SmartCAN :
    - 10 kHz set
    - 200 kHz set
- Intregration of a 'virtual machine' that can be programmed via the IDE STRATON (COPALP)
  - PLC Engine IEC61131-3
  - Communication stack
    - IEC60870-5-101 (S)
    - IEC60870-5-104 (S)
    - IEC61850
- Installation & Configuration simplified as much as possible




The ALPTEC-3000's data can be retrieved remotely either by modem RTC, GSM GPRS or HSPA (3G) or by Ethernet wire. The latter is usually favoured as the communication costs involved are

lower and the data rate higher. Measures are retrieved on a daily basis by a remote reading server operated by EDF R&D. They are saved (with a back up for redundancy) on a server dedicated to the storage of measuring series data. An audit of the power quality (as defined in the CEI 61000-4-30) is carried out monthly as well as an additional, deeper, analysis of the voltage and current harmonics that uses specific software (such as SAV or PQHM) to focus on the assessment of the impacts of the new usages.

*Table 1: Technical specifications of the ALTEC-3000*

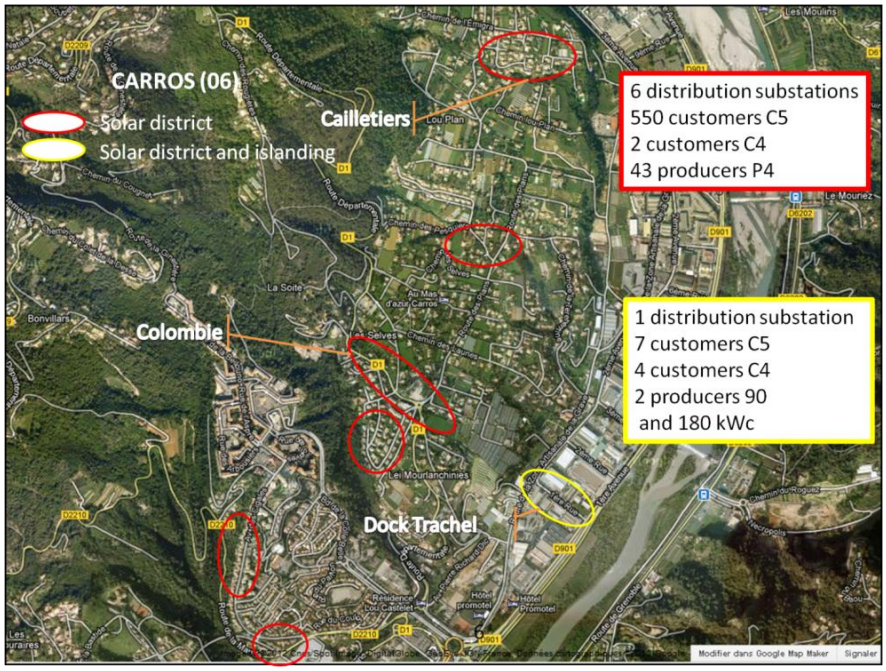
| | |
|---|---|
| Parameters monitored: | Average effective values at the 200 ms (not logged), 3s, 1à min, 1 h, 24 h. |
| Frequency: | 45-57,5Hz (optional 60Hz).<br>Sensor resolution: 10 mHz.<br>Intrinsic error: 30 mHz.<br>Class A as per IEC-61000-4-30. |
| Sampling frequency: | 10240 Hz synchronised using the network frequency (PLL).<br><br>Accuracy: 10 cycles FFT (Fast Fourier Transform) – Bandwidth 30-2200 Hz. |
| Voltage drop and surge: | RMS Measure of 1 period, half-period sliding window<br><br>Reference voltage: U ref.<br>Intrinsic error: <1% de Unom.<br>Class A as per IEC-61000-4-30. |
| Flicker: | PST (10-minute average), PLT (2-hour average).<br>Measures respecting IEC-61000-4-15<br>Measuring range: 0-20.<br>Intrinsic error: <5% de Unom.<br>Class A as per IEC-61000-4-30. |
| Voltage harmonic: | Measuring range: H2 – H51.<br>Measurement steps: 200 ms, 10 min, 1 h, 24h.<br>Measures respecting IEC-61000-4-7 Class I.<br>Class A as per IEC-61000-4-30. |
| Current harmonic: | Measuring range: H2 – H51.<br><br>Measurement steps: 200 ms, 10 min, 1 h, 24h.<br>Measures respecting IEC-61000-4-7 Class I.<br>Class A as per IEC-61000-4-30. |
| Phases unbalance : | Class A as per IEC-61000-4-30. |
| Active power: | As per IEC-61036 class 2. |
| Reactive power: | As per IEC-61268 class 2. |

| | |
|---|---|
| Distortion power | As per IEC-61036 class 2. |
| Shape of the voltage and current wave | Shape logged in case of a voltage or current event. |

Before the installation of the ALPTEC-3000 in July 2014, the Dock Trachel substation was already fitted with a monitoring system. Indeed, an ALPTEC-2444i had been installed for around two years. It monitored the rapid variations of the power needs (3-second step values) to evaluate the performance required of the systems that will be installed for the islanding experiment (including the battery inverters). Despite the number of parameters logged by this system, it was not able to give a description of the state of the grid that differentiated the state of the different feeders, thus its eventual replacement by the ALPTEC-3000.

A feeder by feeder description is indeed necessary to the project in this district. This is due to the fact that this substation distributes the electricity to the largest PV producers of the project and that each of them has their own dedicated feeder.

Even though the ALPTEC-2444i was not advanced enough for the monitoring of the 'Dock Trachel' substation given the requirements linked to the islanding experiment, it proved its utility. That is why the Cailletiers substation has also been fitted with ALPTEC-2444i for the past two years, and the Colombie substation should soon have its own too.



### 2.2.6 Usage of PowerFactory to extend the results

- **What is PowerFactory?**

Power Factory is a power system modelling software developed by DIgSILENT. It has been extensively modified by experts at ERDF to tailor it to the needs of the distribution system operator and namely to the field of opportunities opened by Smart Grid applications.

The distribution network and its characteristics (geographical as well as technical) are wholly modelled in the software that can run calculations to assess the state of the network given a set of consumption and production curves. It is even capable of running asymmetrical calculations on the three phases of low voltage networks, using the phases given by the LINKY meters.

The outputs can be customised to provide the user with information regarding the load of the lines, the voltage at different points of the network, the aggregated power by feeder, or any other electrical data.

- **Application to the project**

The objective was to use the power data recorded by LINKY and PME-PMI meters during the different NICE GRID experimentations to try and scale their results up by running calculations on districts with increased production and increased number of engaged consumers.

Indeed, the number of producers in the seven solar districts, while higher than average, is still too low to really face issues of increased voltage despite the efforts that went into recruiting customers to the project (see Appendix I). A good example is that none of the residential district is currently facing the risk of having more production than consumption during the day. Similarly, even though the engaged customers already have an impact on the aggregated load curves (see Appendix II), the number of customers that accepted to move their consumption on ‘solar days’ would also be insufficient if the production was to reach a more considerable level (according to Appendix II, compensating one 3 kW PV producer would require one engaged customer).

All in all, analysing the results of the experiments provides us with important feedback on how the grid copes with a small increase in PV production and with the current variations of the load over the day.

The idea is to check that PowerFactory provides us with reliable models of the solar districts’ power systems by comparing the voltage variations obtained by running calculations on the LINKY and PME-PMI power data.

If the models proved to be reliable, the next step would be to multiply the penetration of PV production by a coefficient to simulate the future growth of PV production and to assess when constraints really start to appear on the network. Then, replicating the behaviour of engaged customers that move their consumption to the afternoon when incentivised to would allow us to evaluate the ratio of engaged consumers necessary to alleviate the constraints caused by PV production and to check whether the conclusions of Appendix II are confirmed when PV is introduced on a larger scale.

The comparison of the LINKY data on voltage with the results given by the PowerFactory model is detailed in Appendix III. The scaling up of the experiment using PowerFactory is presented and analysed in Appendix IV.

### 2.2.7 Conclusion

This report introduced the various devices installed in the field to monitor the daily behaviour of the grid in the NICE GRID project. These devices are essential to the project and to Smart Grids in general as getting a better knowledge of the distribution network constraints is necessary if we want to manage them more efficiently.

A first round of analysis was then carried out on the data recorded by the project. It highlighted the links that exist between parameters directly related to the customers connected to the low voltage network, such as demand and production, and parameters more relevant to the power quality, such as voltage. These links legitimise the angle of the project which is to make the distribution system more efficient by incentivising the customers to have a smarter consumption in order to increase the quality of the power without having to reinforce the network

These analyses also allowed us to estimate the impact of the load shifting from engaged customers. This is an essential piece of information as it directly impacts the number of engaged customers needed to balance a given number of PV producers.

The next step was to verify the accuracy of the power system model provided by PowerFactory. Having a model of our networks made it possible for us to scale up both the penetration of the PV production and the percentage of customers involved in the project. This gave us an estimation of the level of penetration of PV production that can create voltage constraints on a low voltage network (around 40% for the Colombie substation). It also allowed us to do a first evaluation of the number of engaged customers needed to alleviate these constraints (about one engaged customer per residential producer).

## 2.2.8 Appendices

- **Appendix I – Analysis of the LINKY voltage data**

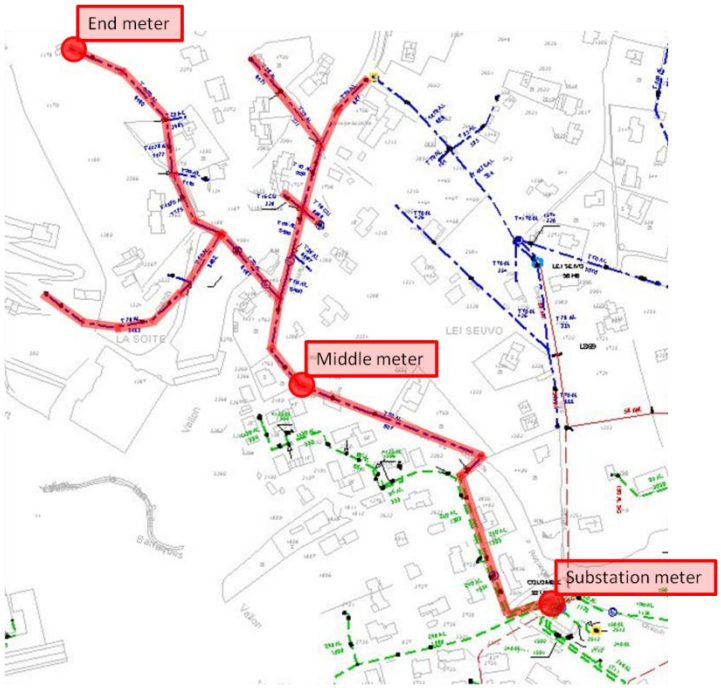
*Scope of the analysis*

Due to the volume of data recorded since the beginning of the project, some choices were made regarding the focus of our analysis.
We studied the data of three summer days in three different solar districts: Cailletiers, Colombie and Lou Souleou. These districts were chosen for several reasons:
They are residential districts that appear likely to be constrained by the penetration of PV production in the future (long LV networks, low demand in the afternoon, many roofs available);
The penetration of LINKY meters was relatively high to provide us with accurate information on the load of each phase;
3-phased meters were available to retrieve voltage data on all three phases at once.

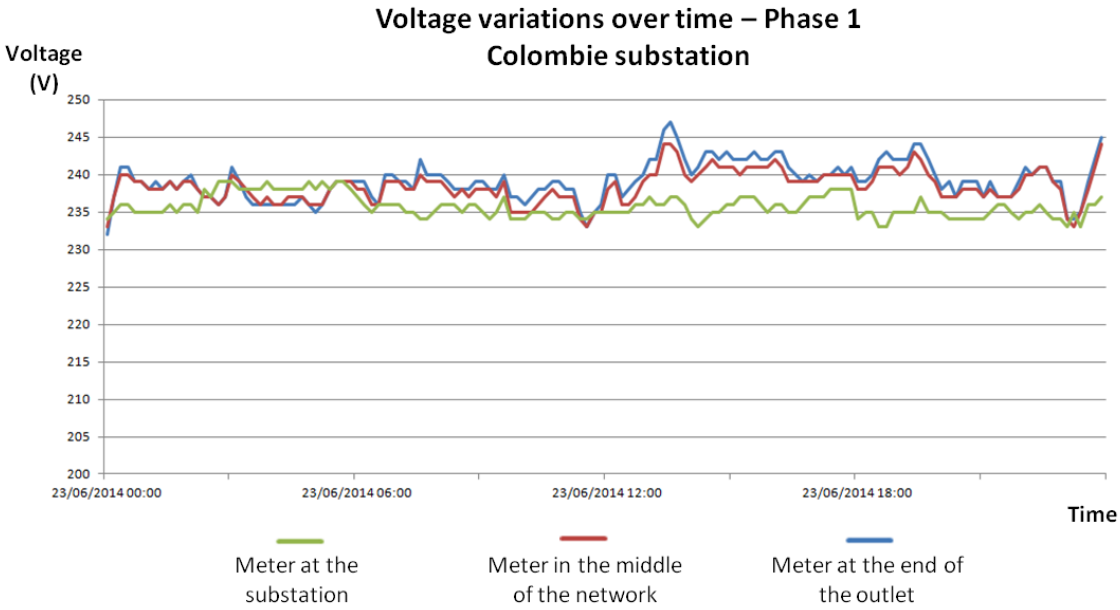
As described in section 2, we selected three meters in each district (near the substation, in the middle of a feeder and at the end of the feeder) to assess the evolution of the voltage over the network during the day.

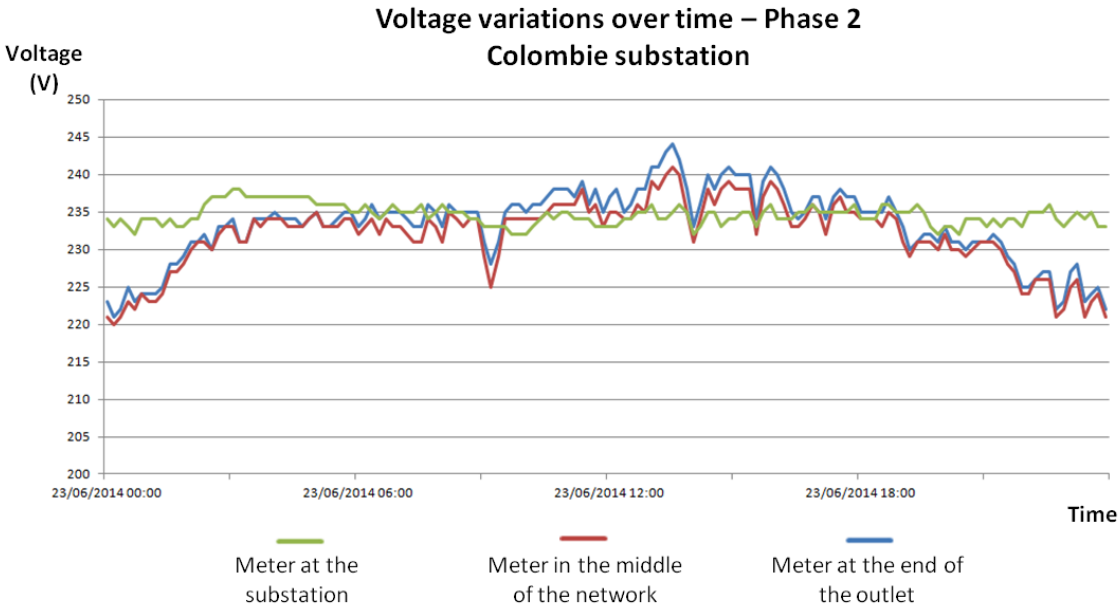
*Evolution of the voltage*

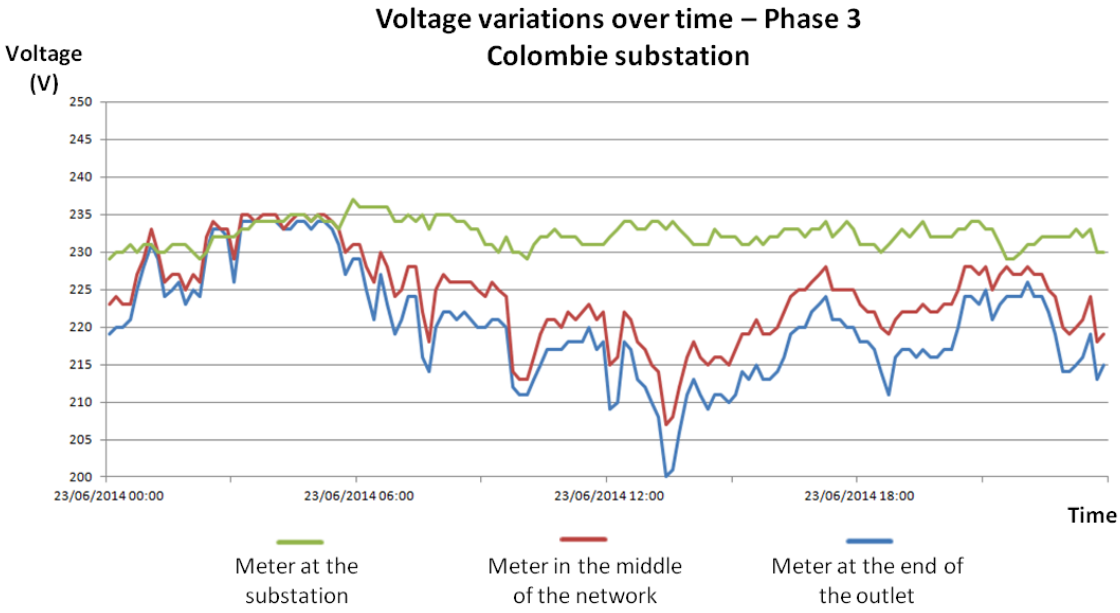
Colombie substation – Feeder 06033001593
This feeder connects 40 customers to the grid. Thirty-two of these customers are equipped with a LINKY meter and four are producers. Three producers are connected on phase 2, while the phase of the fourth one is unknown as it is not fitted with a LINKY meter. The furthest meter on the feeder is 650 m from the substation. The figure below highlights the lines belonging to the feeder and indicates the location of the substation, middle and end of the network meters.




The data we have at our disposal allows us to plot the evolution of the voltage over time. It gives us the figures below.

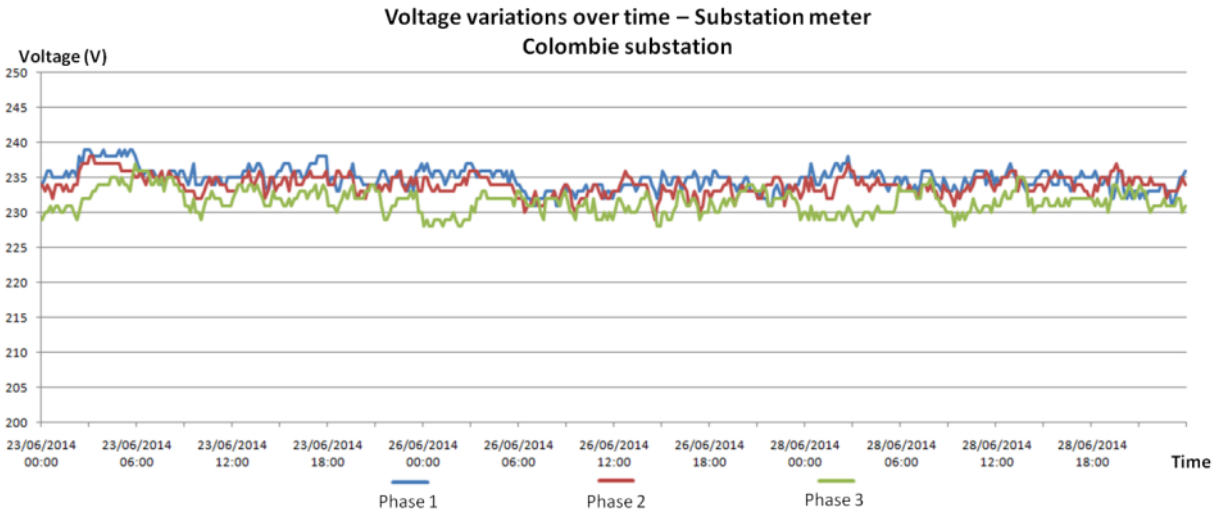


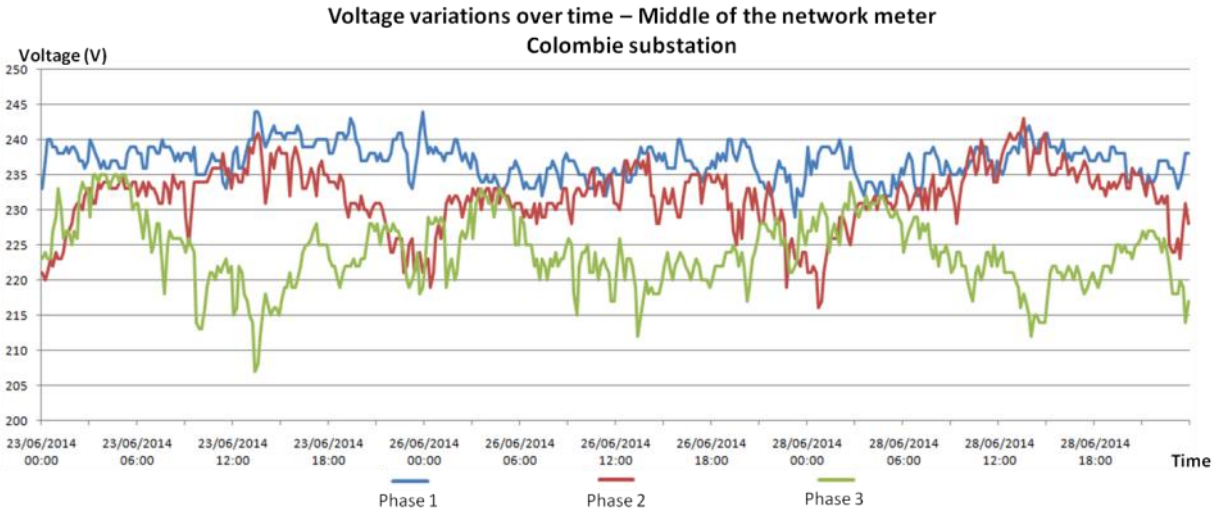


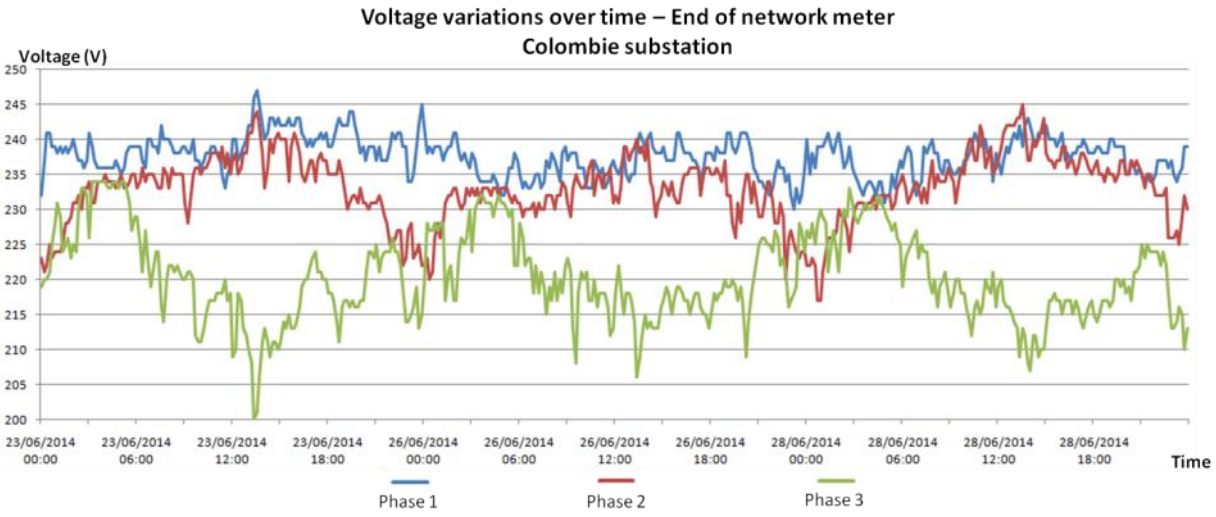




These figures show how the voltage variations tend to grow proportionally the further we get from the substation. As mentioned previously, the voltage variations at the substation are only due to the MV variations. The subsequent variations are due to the different customers (producers and consumers) connected to the low voltage network upstream of the meter which explains why the end meter displays the most important variations.

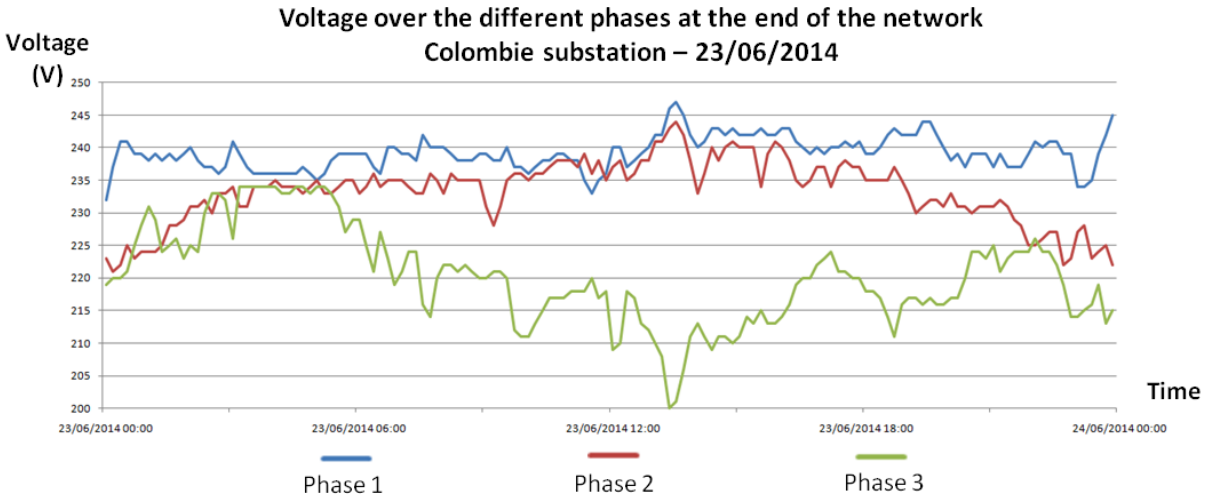
It is also possible to observe the evolution of the three phases on each meter.

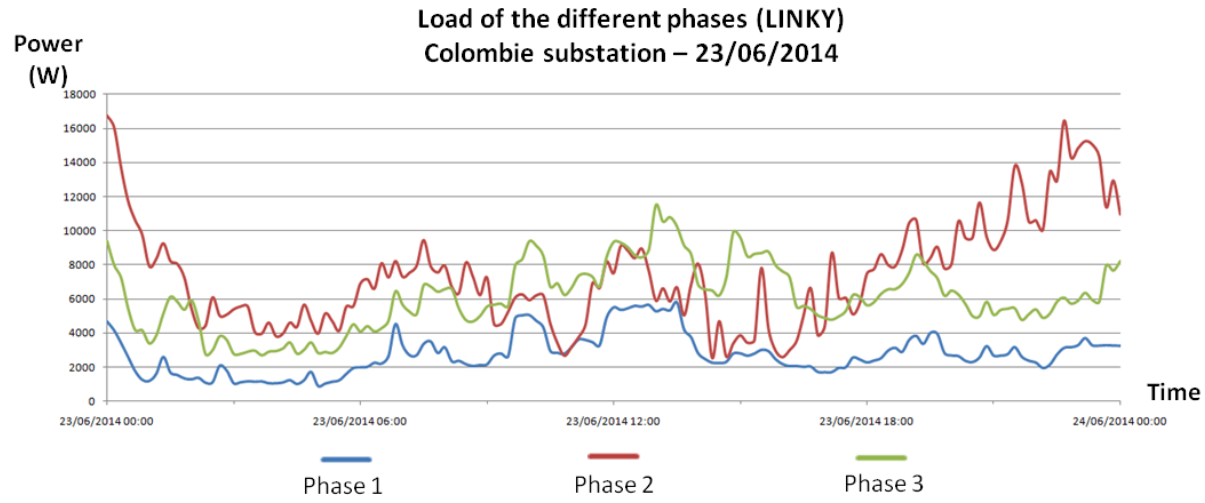

Voltage variations over time – Substation meter
Colombie substation
Voltage (V)
250
245
240
235
230
225
220
215
210
205
200
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
26/06/2014 00:00
26/06/2014 06:00
26/06/2014 12:00
26/06/2014 18:00
28/06/2014 00:00
28/06/2014 06:00
28/06/2014 12:00
28/06/2014 18:00
Time
Phase 1
Phase 2
Phase 3


Voltage variations over time – Middle of the network meter
Colombie substation
Voltage (V)
250
245
240
235
230
225
220
215
210
205
200
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
26/06/2014 00:00
26/06/2014 06:00
26/06/2014 12:00
26/06/2014 18:00
28/06/2014 00:00
28/06/2014 06:00
28/06/2014 12:00
28/06/2014 18:00
Time
Phase 1
Phase 2
Phase 3


Voltage variations over time – End of network meter
Colombie substation
Voltage (V)
250
245
240
235
230
225
220
215
210
205
200
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
26/06/2014 00:00
26/06/2014 06:00
26/06/2014 12:00
26/06/2014 18:00
28/06/2014 00:00
28/06/2014 06:00
28/06/2014 12:00
28/06/2014 18:00
Time
Phase 1
Phase 2
Phase 3

It appears quite clearly that the variations of voltage on the three phases are synchronised and very likely to be created by each other. The next figures focus on the 23/06/2014 and allow a comparison of the evolution of the aggregated load and voltage on each phase.



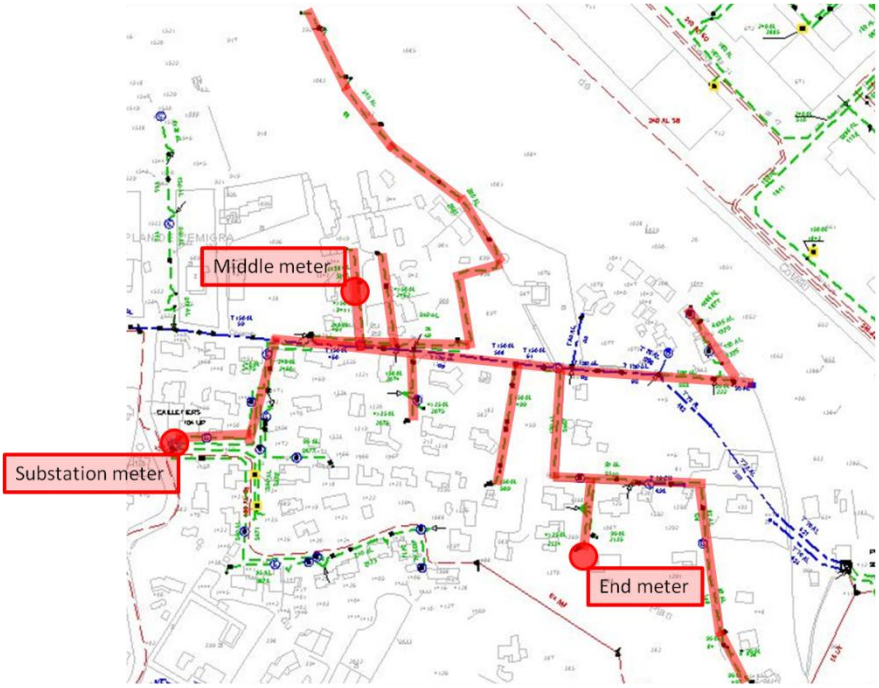

If we analyse the evolution of the voltage by looking at the load curves aggregated by phase, it is possible to explain the global shape of the voltage curves. The minimum in voltage of phase 3 is reached exactly when the load on this phase peaks. At this moment, the system is largely unbalanced as the load on phase 3 is roughly equal to the sum of the loads on the other two phases. This unbalance explains the fact that the voltage on phase 1 and 2 peak at the same time to compensate the drop in voltage on phase 3. On a more general note, phase 1 is the less loaded of the three phases and, quite logically, displays the highest voltage curve.

The fact that the voltage on phase 2 sticks closer to the voltage on phase 1 than to the voltage on phase 3 despite a load that oscillates between those of phase 1 and 3 could maybe be explained by the presence of PV production on phase 2. This production may be the source of local voltage increases.

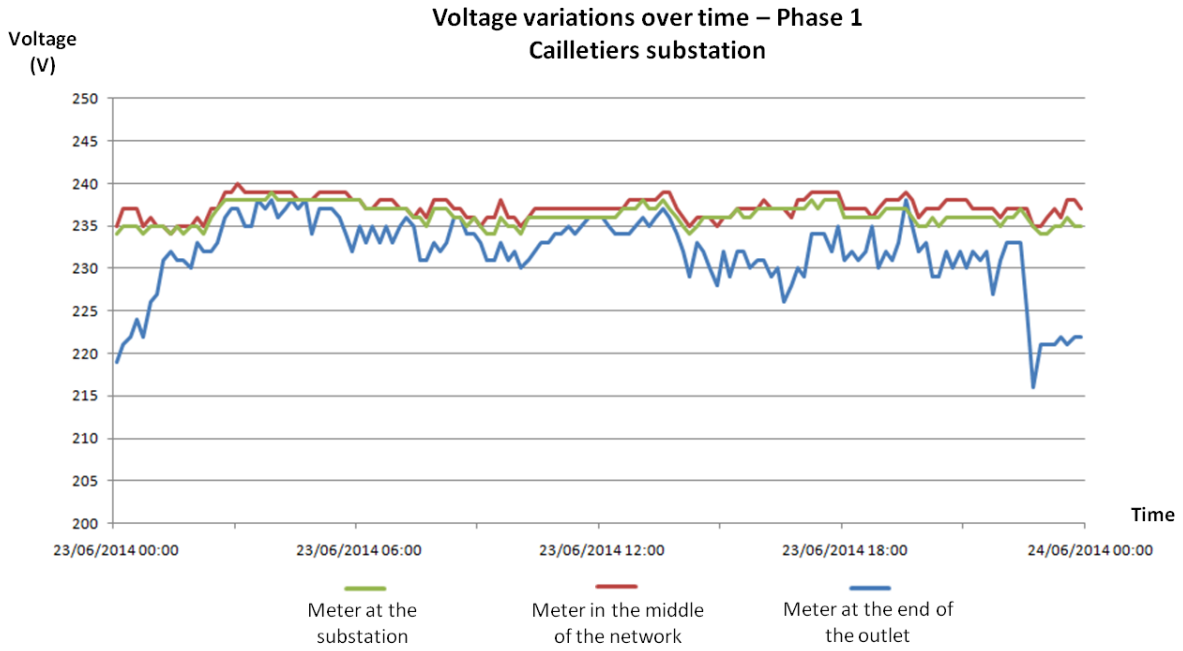
Other features of the voltage figure that cannot be properly explained by the load figure are the variations of voltage on phase 2 from the evening to the late morning. Indeed, phase 2 voltage gets closer to phase 3 but not lower, even though the load curves show clearly that, except during the afternoon, the load on phase 2 is higher than on phase 3. These discrepancies could be linked to the fact that only 80% of the customers connected to the feeder that is being studied are equipped with LINKY meters. This means that about 20% of the load is missing. It is likely that this missing load is not perfectly balanced between the three phases and it could explain discrepancies that are spread over most of the day.

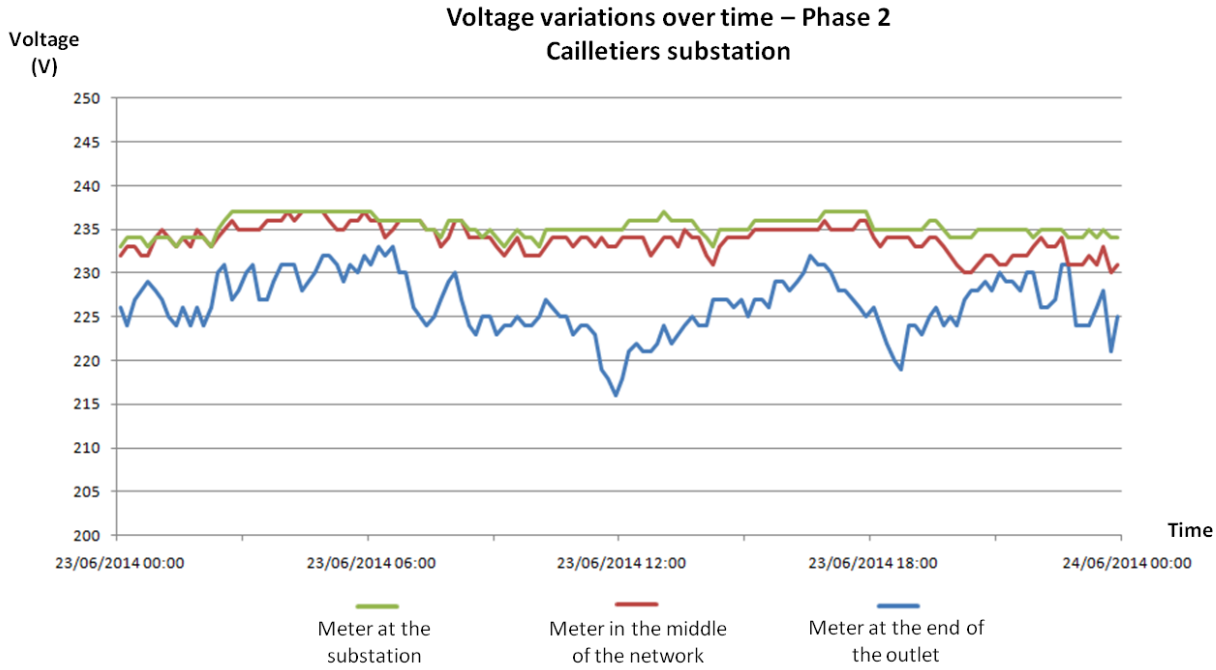
*Cailletiers substation – Feeder 0603302475*

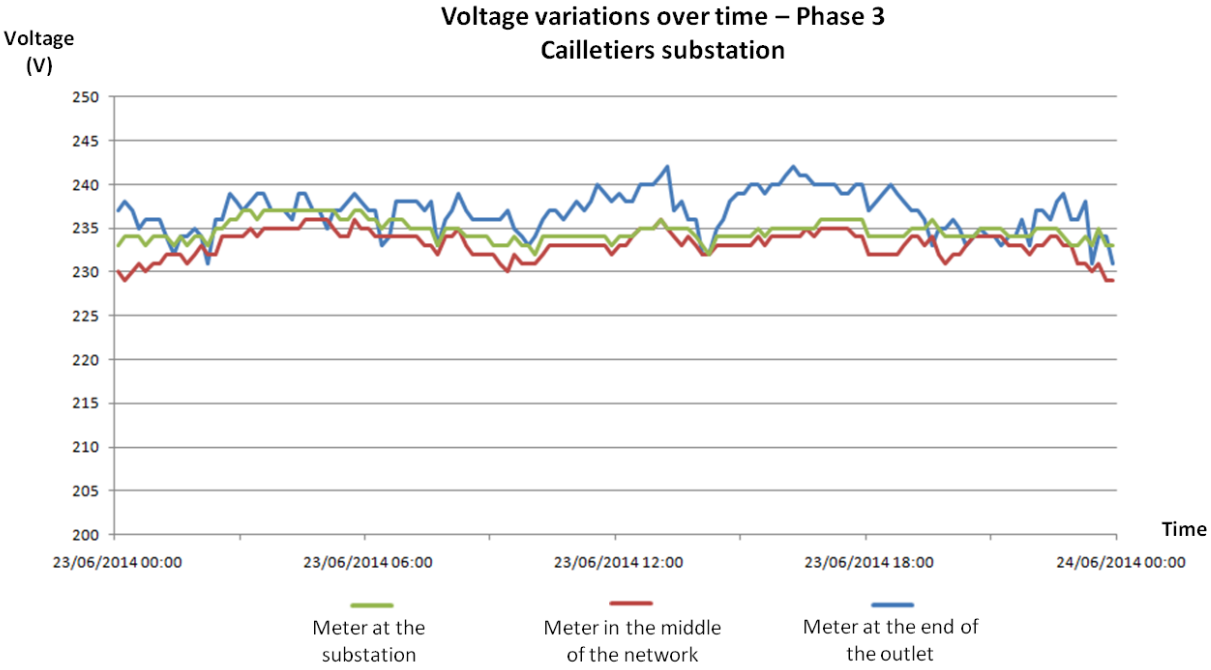
This feeder connects 69 customers to the grid. Fifty-nine of these customers are equipped with a LINKY meter. Six of these customers are producers, two of them are connected to phase 1 and four to phase 3. The furthest meter on the feeder is 540 m from the substation. The figure below highlights the lines belonging to the feeder and indicates the location of the substation, middle and end of the network meters.




The data we have at our disposal allows us to plot the evolution of the voltage over time. It gives us the figures below.

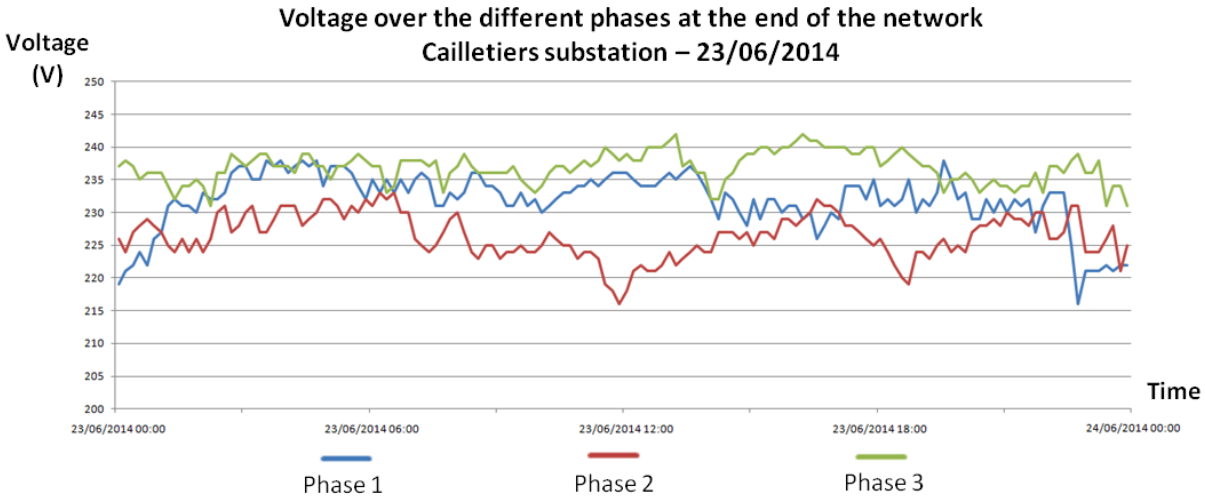

Voltage variations over time – Phase 1
Cailletiers substation
Voltage (V)
250
245
240
235
230
225
220
215
210
205
200
Time
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
24/06/2014 00:00
Meter at the substation
Meter in the middle of the network
Meter at the end of the outlet

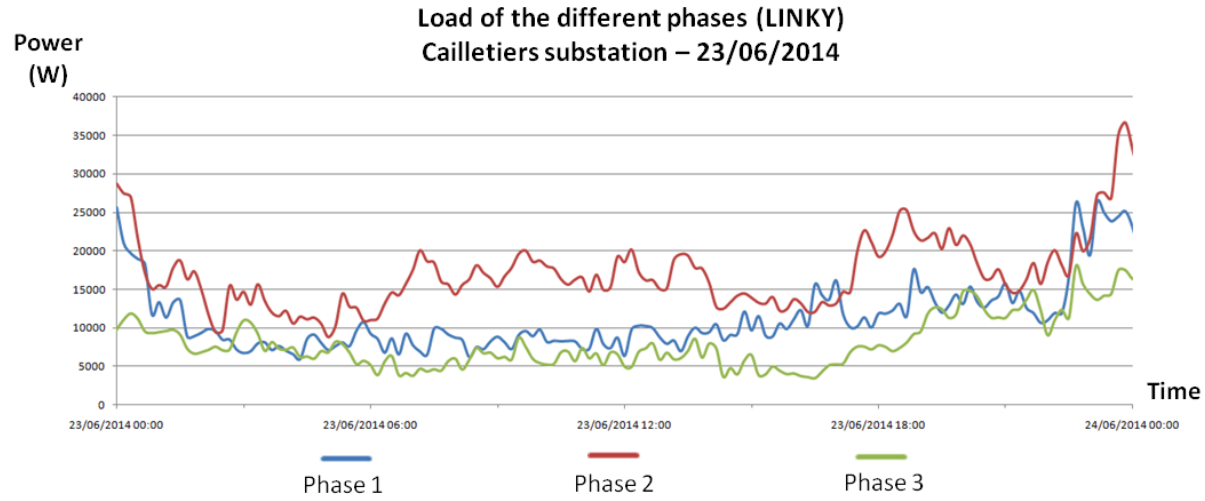

Voltage variations over time – Phase 2
Cailletiers substation
Voltage (V)
250
245
240
235
230
225
220
215
210
205
200
Time
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
24/06/2014 00:00
Meter at the substation
Meter in the middle of the network
Meter at the end of the outlet




On these figures, it is worth noticing that the voltage curves corresponding to the meters at the substation and in the middle of the network are extremely close, especially if you compare them with the curve of the meter at the end of the network. This is due to the fact that despite our commitment to the choice of a meter situated in the middle of the feeder, this choice was based on geographical data. It appears that though this meter is roughly located in the middle of the line, the load is unevenly distributed across the line whose end is much more loaded than its beginning. Therefore, the voltage variations between the middle and the end meters are more significant than the ones between the substation and middle meters.

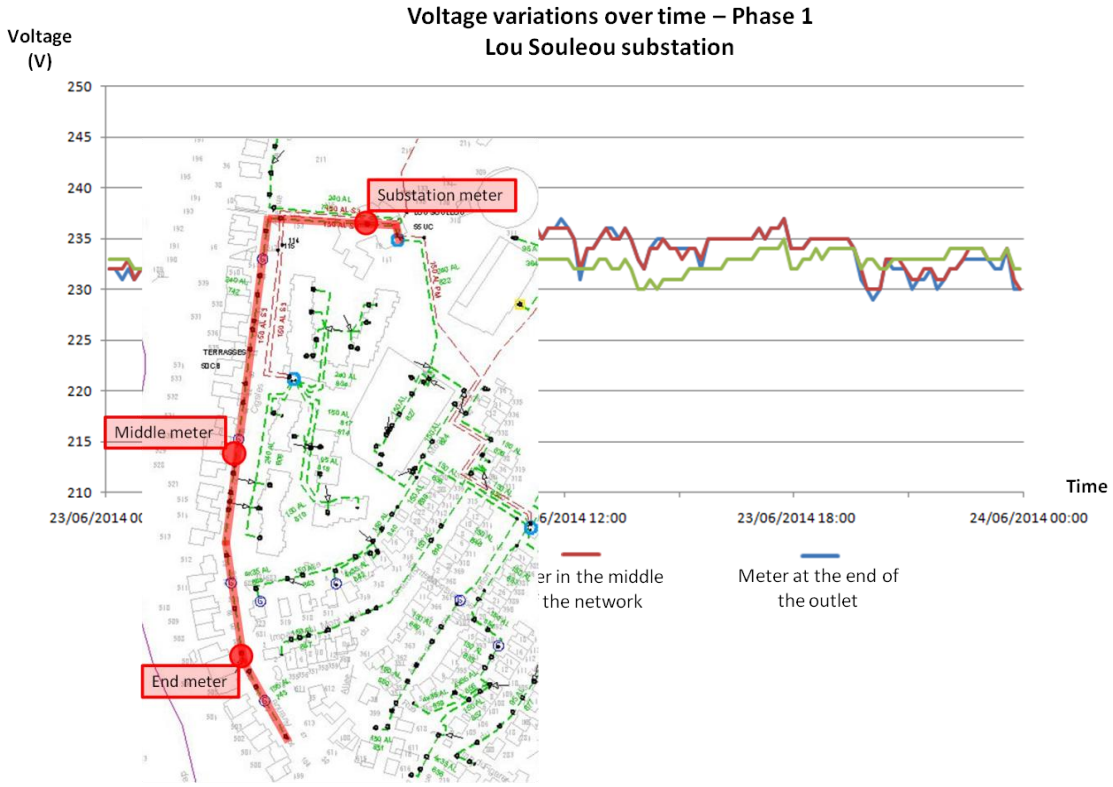
Similarly to the feeder of the Colombie substation, the voltage variations on the three phases are synchronised on the three days studied. We will thus proceed similarly and focus on the 23/06/2014 to try and analyse the cause of these changes by comparing the voltage variations with the load curve of each phase.




The penetration of LINKY meters on this feeder is slightly better than for the Colombie feeder so the comparison of the load with the voltage variations should prove easier. It is quite clear from the graph that, once more, the three phases are not really balanced with phase 2 being the most loaded and phase 3 the least. This translates quite well to the voltage variations where the voltage variations replicate almost all the load variations with the lowest voltage present on the most loaded curve. Even the peak of phase 1's load around 17:00 has a clear impact on the voltage. It is only during the middle of the night that phase 1's voltage drops under phase 2's while its load remains inferior.

The presence of PV can be noticed by comparing phase 1 and phase 2 loads during the afternoon and during the evening. Indeed, the two curves behave in the same way during the evening leading us to think that a similar number of customers are connected to them but they display a gap during the afternoon that is probably due to the fact that there are more producers on phase 1. This production leads to the unbalance of the phases during the afternoon and, indirectly, to the voltage gap.

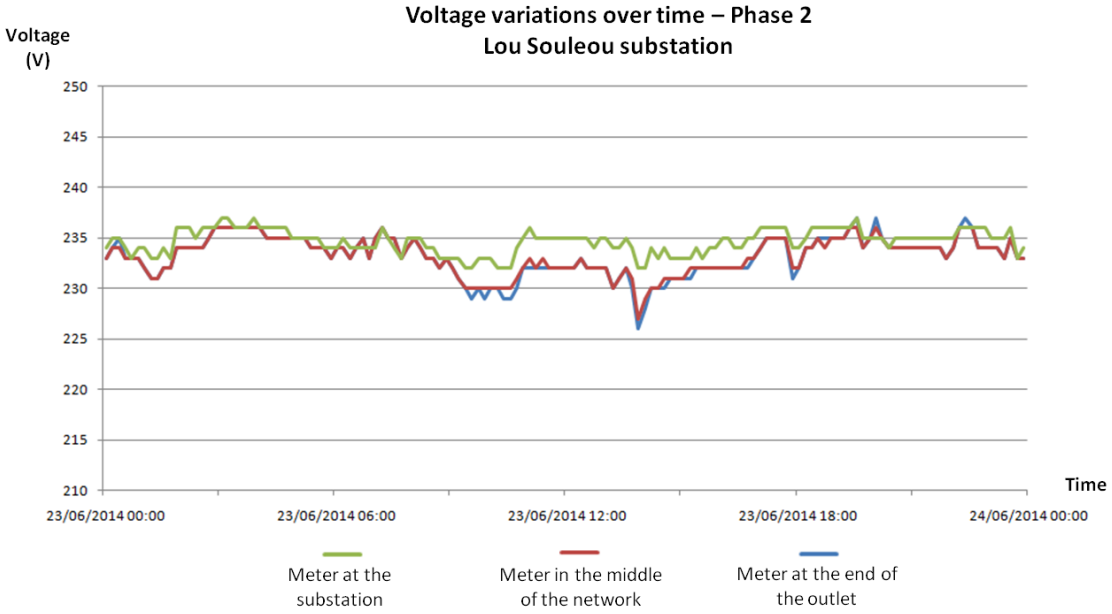


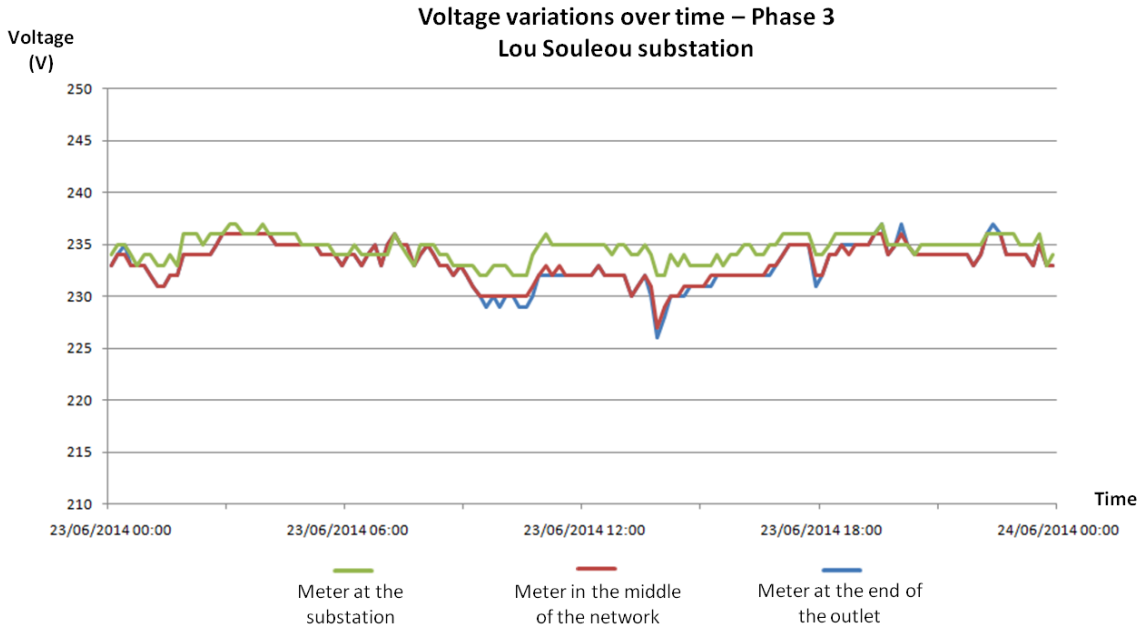

In the end, on this feeder, it proves quite easy to explain the voltage variations via the unbalance of the network. The link between high voltage and low load appears quite strongly and proves resilient to variations of the load during a large part of the day. Still, this also means that the penetration of the production on the feeder is too small to create issues of high voltage as the unbalance of the three phases remains the main driver of the voltage variations.

*Lou Souleou substation – Feeder 0603300742*

This feeder connects 41 customers to the grid. Thirty-seven of these customers are equipped with a LINKY meter. Two of these customers are producers, both connected to phase 1.
The data we have at our disposal allows us to plot the evolution of the voltage over time. It gives us the figures below. The furthest meter on the feeder is 350 m from the substation. The figure below highlights the lines belonging to the feeder and indicates the location of the substation, middle and end of the network meters.

Similarly to the Cailletiers feeder, this feeder displays a load that is unevenly distributed along the line. Even though the middle meter was selected to roughly correspond to the geographic middle of the line, the figures make it quite obvious that most of the load is between the substation and middle meters.



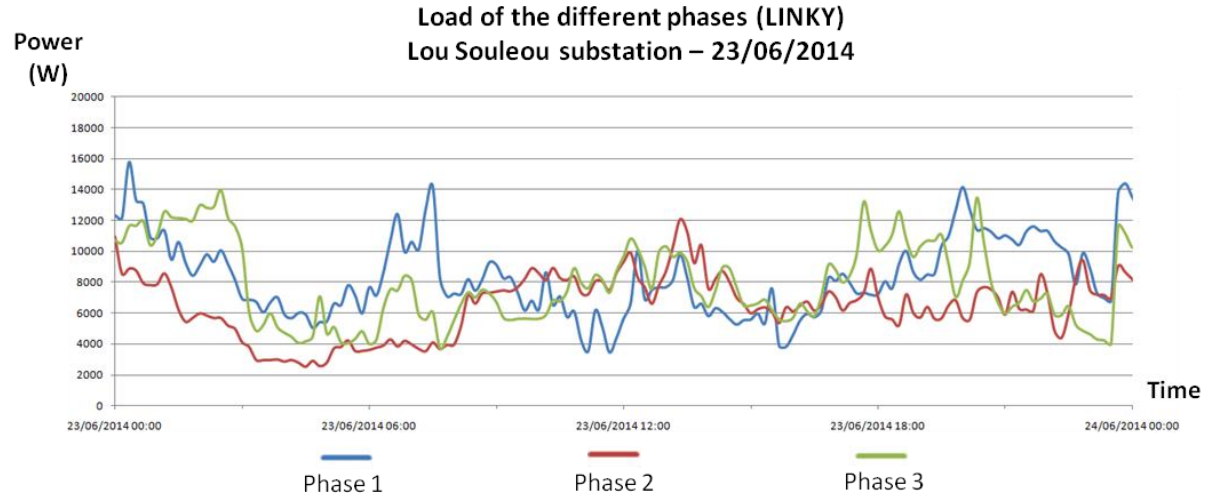

A second feature that should be noticed on these figures is the small amplitude of the voltage variations in comparison with what happens on the Cailletiers and Colombie feeders. This amplitude can be affected by three different factors: the load, the length of the line and the unbalance between the phases (which is directly linked to the load). The Lou Souleou feeder is much shorter than the other two (350 m against 540 m for Cailletiers and 650 m for Colombie) but displays a load superior to the load of Colombie (and inferior to Cailletiers), which is relatively well balanced during the 10:00-18:00 period, ie the period during which most of the voltage variations occur. Thus, the voltage variations in Lou Souleou cannot be due to the unbalance of the phases as we suspected it was the case for Cailletiers and Colombie.

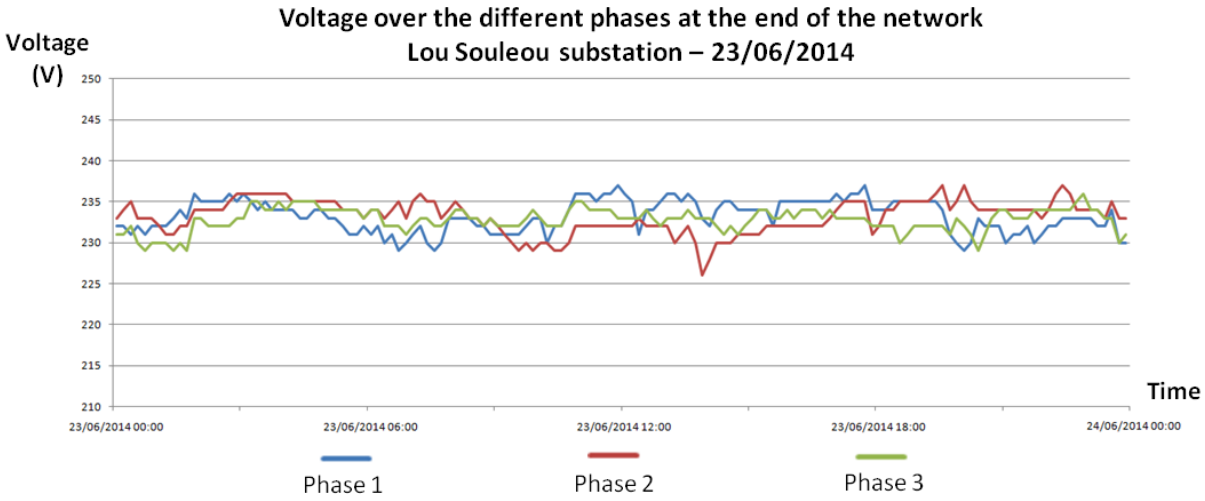
If we focus on the comparison between Lou Souleou and Colombie, the amplitude of the voltage variations is divided by three in Lou Souleou while the load is slightly superior and the line half the length of the one in Colombie. Lou Souleou's higher load should partly compensate the much shorter line length and should at least mean that the voltage variations amplitude is not divided by three.

Thus, the fact that the load is better balanced in Lou Souleou probably has a stabilising effect on

the voltage by preventing any cross-phase impact where a high voltage on one phase entails a low voltage on the others.

If we look at the figures below, we can directly compare the evolution of the load on the three phases with the voltage variations.The high penetration of LINKY meters on this feeder (90%) leads to a fairly accurate match up of the load and voltage variations on a phase-by-phase basis. This is reinforced by the lack of cross-phase impact that was mentioned before.




Conclusion on the evolution of the voltage

This analysis focused on a few selected feeders of substations that are likely to be constrained in the future because of PV production in the afternoon at a time where the demand is quite low. The feeders were also chosen to have a high penetration of LINKY meters, so that the information at our disposal was as comprehensive as possible.

Given the currently low penetration of PV producers (less than 10%), it proved difficult to assess their impact on voltage beyond the fact that they reduce the load on their phase during the afternoon thus indirectly increasing the voltage (as showed by the fact that the phases where PV producers are connected are often the least loaded during the afternoon).

In the end, most of the voltage variations are linked directly to the evolution of the load on the three phases. When one phase is clearly the most (resp. the least) loaded, it tends to have the lowest (resp. the highest) voltage and to increase (resp. decrease) the voltage on the other phases. Thus, the unbalance of the phases was one of the main reasons behind the largest voltage variations as it often amplified the variation due to the load by adding cross-phases effects.

## ▪ Appendix II – Analysis of the LINKY power data and estimation of the load shifted by engaged customers

*Scope of the analysis*

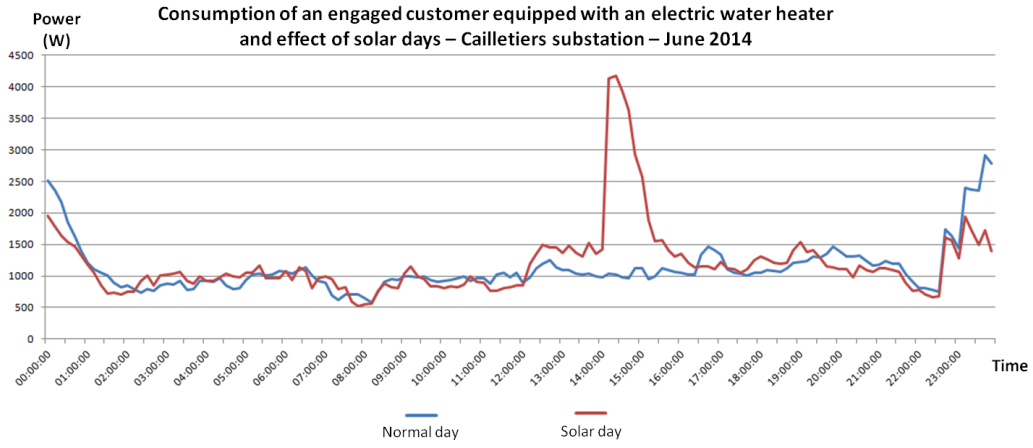
This analysis focuses on the first month or so of the 2014 summer experiment. It uses the power data recorded by the LINKY meters over the period 30/05/2014 - 09/07/2014 to assess the volume of energy that engaged customers shifted to the afternoon when they were incentivised to by the project.

It is only a first analysis of the effect the incentive has on the customers' behaviour. It focuses only on customers equipped with an electric water heater and connected to the Cailletiers feeder n°0603302475.

EDF is in charge of the more detailed analysis of the customers' behaviour during the 2014 summer experiment.

*Evolution of the consumption*

Using the project's databases, it was possible to single out the load curves of the customers that have their electric water heater turned on remotely during the summer experiments and to compare their usual consumption with their consumption over a 'solar day' during which they are incentivised to shift their consumption to the 12:00-16:00 period. The figure below plots the average consumption of an engaged customer on a 'normal day' (blue) and on a 'solar day' (red).



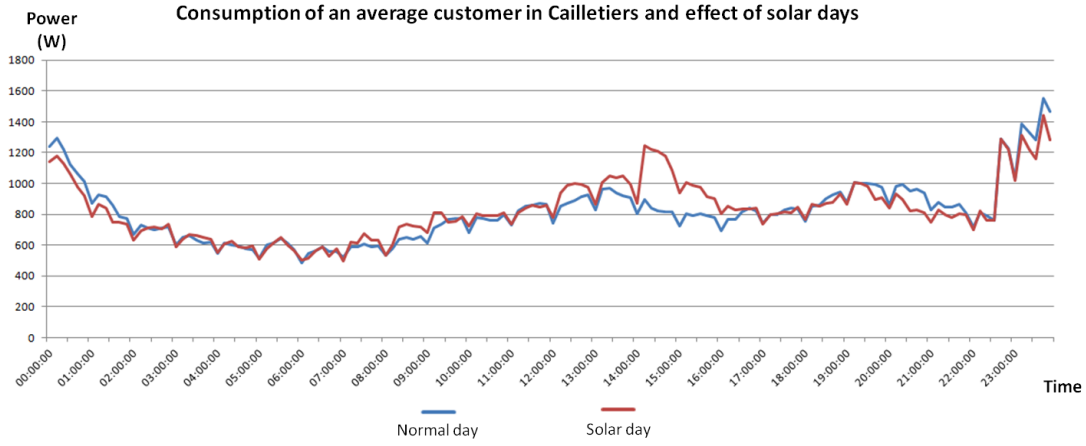

The load shift is proven quite efficient with a large increase of the consumption during the solar period. The consumption increase during the 12:00-16:00 period can be divided into two. At first, there is a clear peak in consumption that is due to the electric water heaters that are triggered remotely at 14:00. This peak only lasts for one hour as the heaters switch off when all the water has been heated. During the rest of the period, the increase in consumption is less important as it is only based on more classic usages such as washing machines. The load shift during this second

hour is similar to the load shift of an engaged customer that doesn't have an electric water heater (about 500 W).

The average total consumption over the 12:00-16:00 period is 8.5 kWh for an engaged customer with an electric water heater turned on remotely and only 3 kWh for a classic customer. Thus it would seem that, energy wise, one engaged customer and one classic customer would on average consume the production of a typical 3 kWp PV installation. However, this is not reflecting the actual power variations.
To balance a PV installation both power wise and energy wise, it would be necessary to smooth the 14:00-15:00 peak and to spread it over the whole solar production period. This could either be achieved by controlling the power of the water heaters to make sure they need the whole period to heat all the water or, more easily, by having the electric water heaters triggered successively – similarly to what is already done with electric water heaters during the night in France.

*Effect at the feeder level*

Five of the fifty-three LINKY-equipped consumers of the Cailletiers feeder studied in Appendix I are participating in the summer experiment. The previous section gave us an estimate of the average load shift that is achieved by each of them and we will now assess their effect on the global load of the feeder. The figure below plots the consumption of an average customer on a 'normal day' (blue) and on a 'solar day' (red) (all customers are aggregated whether they are engaged or not in the project).




This figure shows that even with only 10% of the consumers engaged in the project, the effect on the load curve is already noticeable.

*Conclusion*
This analysis focused on the impacts of incentivising a customer to shift its consumption to the afternoon on days of important solar production. It showed that even with only 10% of customers engaged in the project, we already have results that can be noticed by looking at aggregated curves.

Looking at the volume of load shifted by an engaged consumer also allowed us to give a first estimate of the number of engaged customers needed to compensate – power wise – the presence of residential PV producers (one engaged customer and one classic customer per producer should be enough). Moreover, this study highlighted the need to refine the solar period process in order to spread the current 1-hour peak over the whole solar production period; this could be achieved by triggering the electric water heaters successively rather than all together at the start of the period. While this is currently done at a national level with electric water heaters during the night in France, it would be much more difficult to implement in our context because of the small number of customers per feeder (around 50 customers, only 10 to 20% of those take part in the load shifting) which make the aggregation more complex. It may be more efficient to target larger groups of customers, perhaps by looking at MV feeders rather than LV feeders.

Finally, while we gave an estimate of the number of engaged customers needed to compensate the presence of PV producers. This estimate was only based on considerations regarding the production and the demand. While this should translate into reduced voltage variations, it is still necessary to check that this is true – especially if the volume of production and the number of engaged customers are increased. This will be addressed in Appendix IV.

- **Appendix III – Comparison of the voltage variations measured by the LINKY meters with the calculations run on PowerFactory**

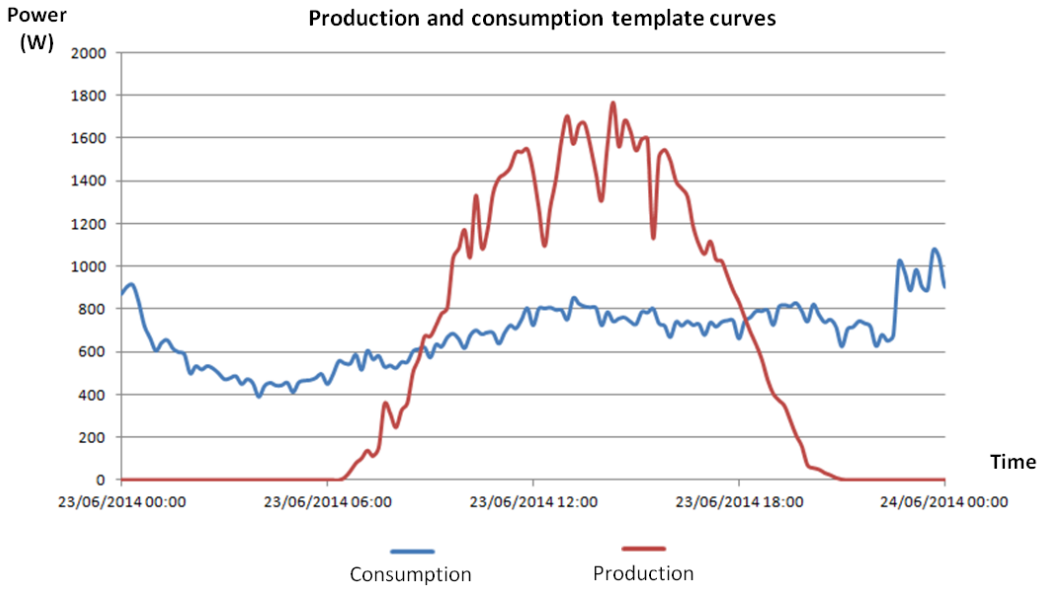
*Scope of the comparison*

This comparison is based on the LINKY data that was analysed in Appendix I.

The load curves of all the consumers and producers fitted with LINKY meters are inputted into the PowerFactory models of the three solar secondary substations named Colombie, Cailletiers and Lou Souleou. The analysis is done on the three feeders that were detailed and displayed in Appendix I. The table below summarises some information on them.

| | **Colombie 06033001593** | **Cailletiers 0603302475** | **Lou Souleou 0603300742** |
|---|---|---|---|
| *Length of the feeder* | 650 m | 540 m | 350 m |
| *Number of consumers (number of LINKY equipped consumers)* | 36 (29) | 63 (53) | 39 (35) |
| *Number of producers (number of LINKY equipped producers)* | 4 (3) | 6 (6) | 2 (2) |
| *Phase of the producers* | 3 on phase 2<br>1 unknown | 2 on phase 1<br>4 on phase 3 | 2 on phase 1 |

The consumers (resp. producers) who have not been equipped with a LINKY meter are given a template load curve which corresponds to the average consumption (resp. production) of all LINKY equipped customers.

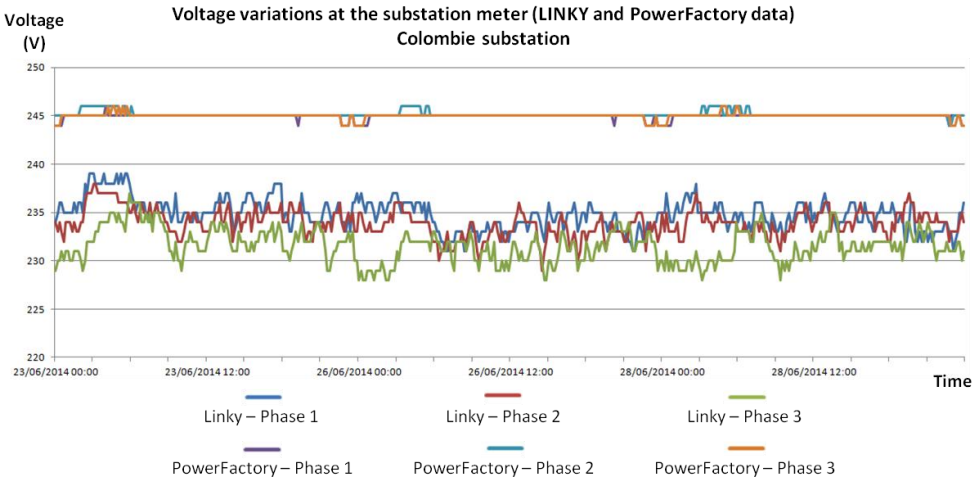



Once all the consumers and producers of a substation have their load curve, calculations are run and the voltage data is exported.

It is then possible to compare the voltage variations of the PowerFactory model with the ones measured by LINKY to assess the reliability of PowerFactory as a modelling tool of our low voltage networks.

### *Focusing on the low voltage network voltage variations*

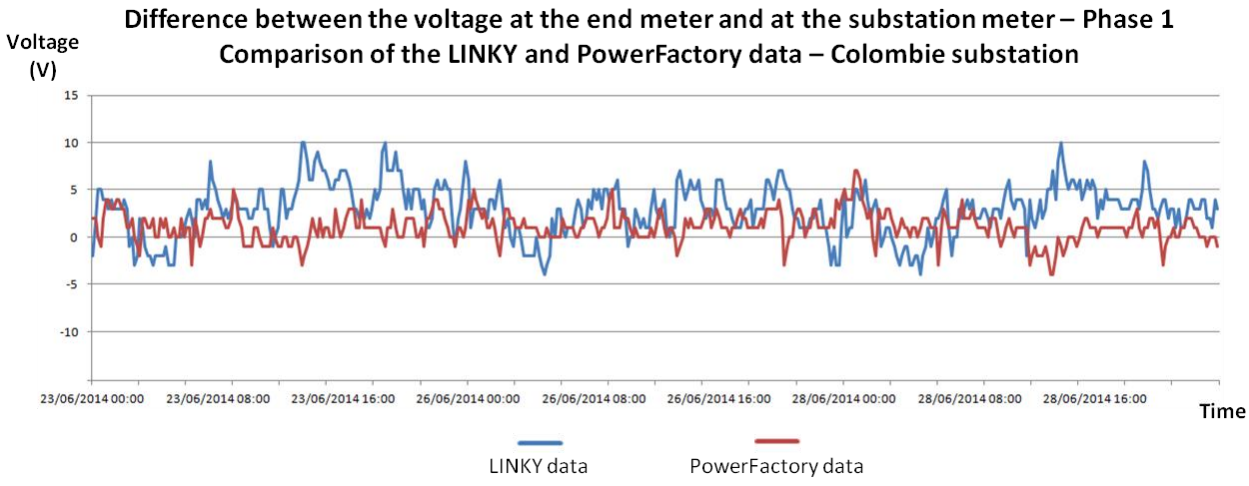
As no MV voltage data was inputted into the PowerFactory model, the voltage baseline at the substation is considered as constant in the model calculations. As we have seen in Appendix I, this is not the case in real life where the voltage at the substation varies constantly. The next figure displays the differences between the two sources of data (the PowerFactory calculations and the LINKY measures) for the Colombie substation.

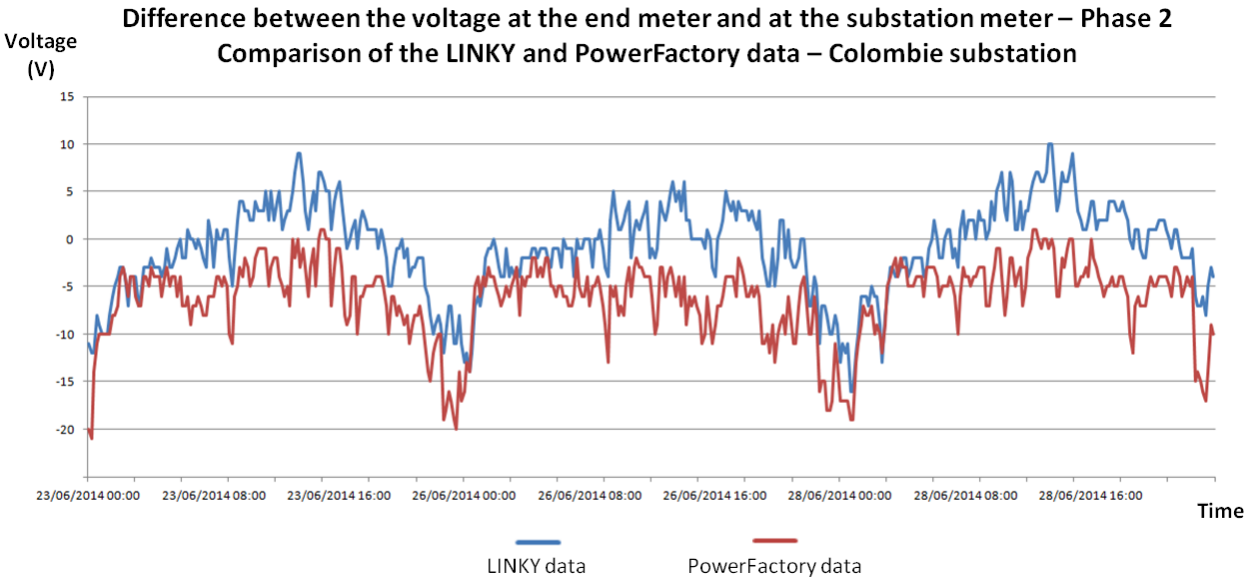


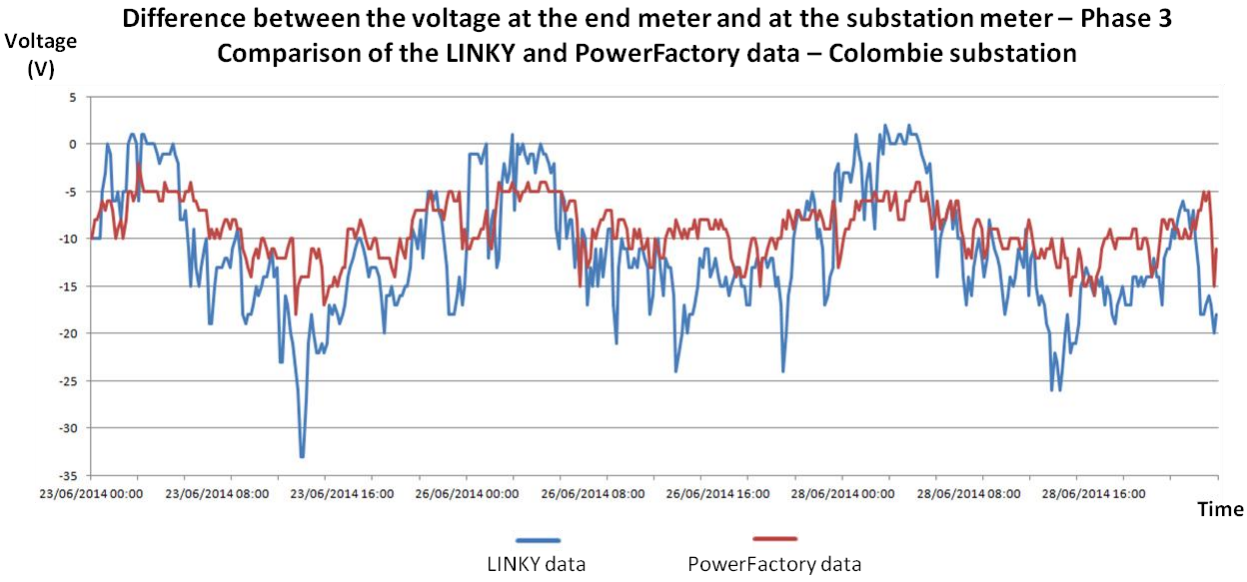

As we want to focus on the model's reliability when it comes to the voltage variations caused by the low voltage network, we decided to mask the variations caused by the upstream network at the secondary of the transformer. This is done by working on the difference between the voltage at the end/middle of the network meters and the voltage at the meter located close to the substation rather than directly on the voltage at the end/middle of the network meters. This makes the voltage data of both sources comparable without having to input MV voltage data into PowerFactory.

### *Comparison of the voltage variations*

We can then plot the voltage variations over the low voltage network using the data supplied by the LINKY meters and the PowerFactory model. For the Colombie substation, it gives us the three figures below.






The results of phase 1 are not very satisfactory but it must be noted that there are very few customers with LINKY meters connected to this phase. Most of the load connected to phase 1 is thus obtained either by inputting profiled curves and by assuming that the load of the 3-phase customers is evenly distributed on the three phases – which is not always true. Moreover, as the

voltage variations on the LV network are quite small for this phase, it is much more likely to display residual impacts of the MV voltage variations that would not have been masked by our method.

Phase 2 and 3 are better equipped with LINKY meters and the comparison of the voltage measures with the PowerFactory results is much more satisfactory. The variations of voltage measured by LINKY meters are mirrored by the results of the model and the curves seem to be well synchronised. When differences between the two sources of data occur, they represent a difference in the amplitude of the variations not an opposition of sign. These differences regarding the amplitude of the variations can be explained by the fact that only 80% of the customers on this feeder are equipped with LINKY meters.

*Conclusion on the comparison of the PowerFactory and LINKY voltage data*

We have seen that despite the several approximations that are made in our study, including the assumption that 3-phase customers have a perfectly balanced load, the usage of up to 20% of profiled loads, the bypass of the MV voltage variations and the assumption that the 10-minute step values are synchronous, the results of the model are fairly close to the measures of the LINKY meters.

This leads us to conclude that the calculations are reliable as long as the description of the network (especially the position and the phase of the customers) is accurate. Getting a high quality picture of the networks and of their customers is thus the main challenge for network operators who plan on modelling them.

- **Appendix IV – Scaling up the results of the experiments with PowerFactory**

*Objectives*

Appendix III concluded that when the description of a network is accurate (characteristics of the equipments, connection to the phases, load curves), the results of the PowerFactory calculations are close to the measures collected by the LINKY meters.

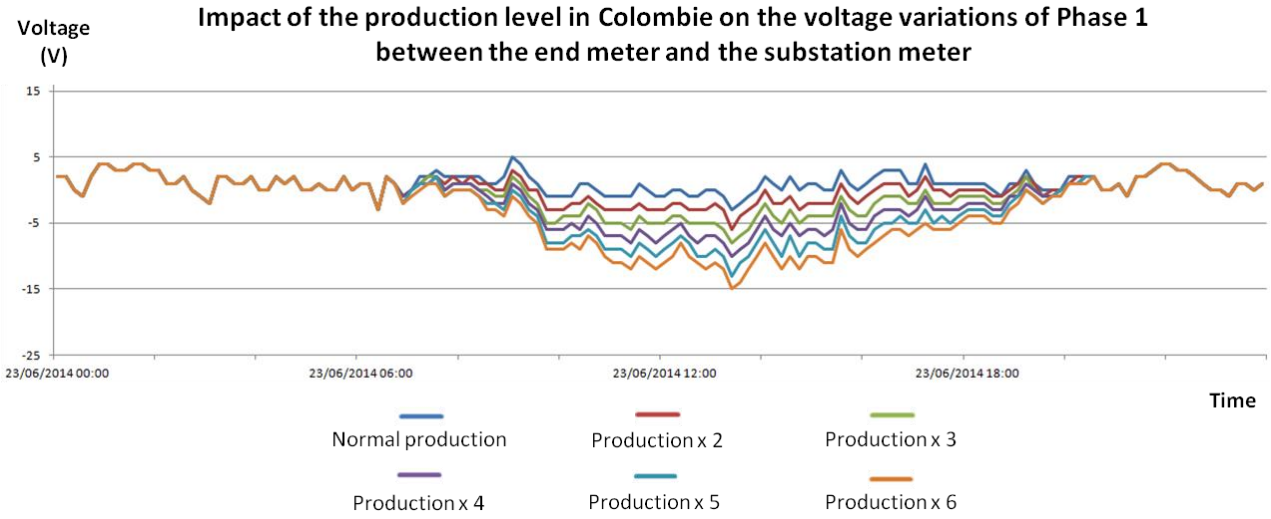
This makes it possible for us to use PowerFactory in order to estimate how the network would respond to increased levels of production, when high voltage constraints would start to appear and to what extent engaged customers could alleviate these constraints.

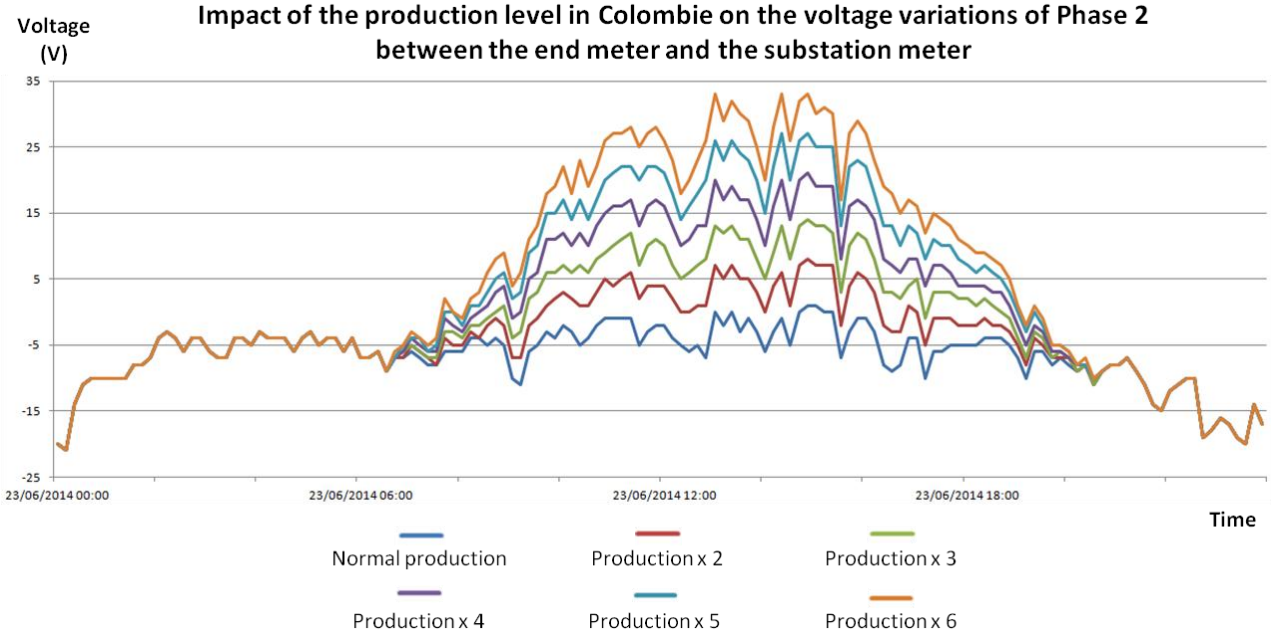
We focused on the Colombie feeder studied in Appendix I and on the 23/06/2014. When increasing the number of engaged customers, we focused on the customers equipped with an electric water heater.

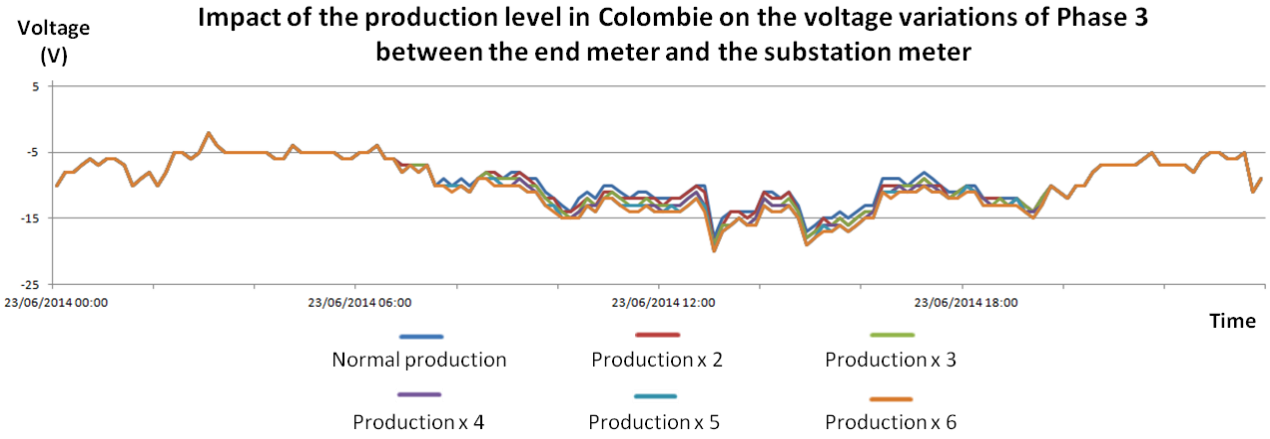
| | *Length of the feeder* | *Number of consumers (number of LINKY equipped consumers)* | *Number of producers (number of LINKY equipped producers)* | *Phase of the producers* |
|---|---|---|---|---|
| **Colombie 06033001593** | 650 m | 36 (29) | 4 (3) | 3 on phase 2<br>1 unknown |

*Reaction to the increase of the PV production*

The increase of the PV production was simulated by multiplying the power of the existing installations rather than creating new ones. This approximation can have some local impacts but the voltage variations calculated by PowerFactory should still be quite representative of the situation on the feeder.


Impact of the production level in Colombie on the voltage variations of Phase 1 between the end meter and the substation meter
Voltage (V)
15
5
-5
-15
-25
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
Time
Normal production
Production x 2
Production x 3
Production x 4
Production x 5
Production x 6


Impact of the production level in Colombie on the voltage variations of Phase 2 between the end meter and the substation meter
Voltage (V)
35
25
15
5
-5
-15
-25
23/06/2014 00:00
23/06/2014 06:00
23/06/2014 12:00
23/06/2014 18:00
Time
Normal production
Production x 2
Production x 3
Production x 4
Production x 5
Production x 6




The impact of the increase in production is very clear on these figures. We saw in Appendix I that all the production was connected to Phase 2 and there is a large increase in voltage on this phase during the 8:00-20:00 period. This increase in voltage is compensated on the other phases by a synchronised decrease, similarly to the cross-phases impacts that were highlighted in Appendix I.

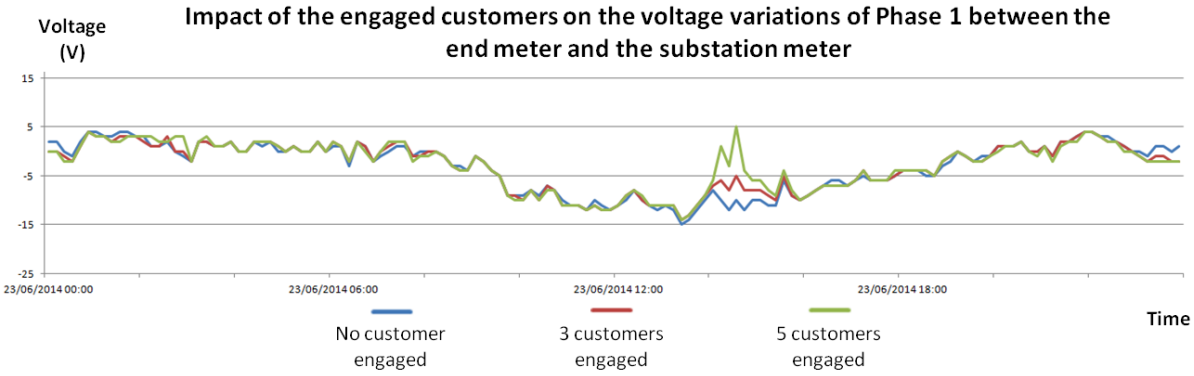
According to French regulation, the voltage should remain within the 230 V +/-10% range (ie between 207 V and 253 V). Our simulations allow us to see that when we reach a production multiplied by four, we can have voltage variations going from – 10 V to + 20 V. Given that the +/-10% range is also supposed to cater for the MV voltage variations, we can assume that such a level of production could eventually lead to breaching the regulation. In the case of the feeder we are studying, multiplying the production by four is equivalent to a penetration ratio of around 40%.

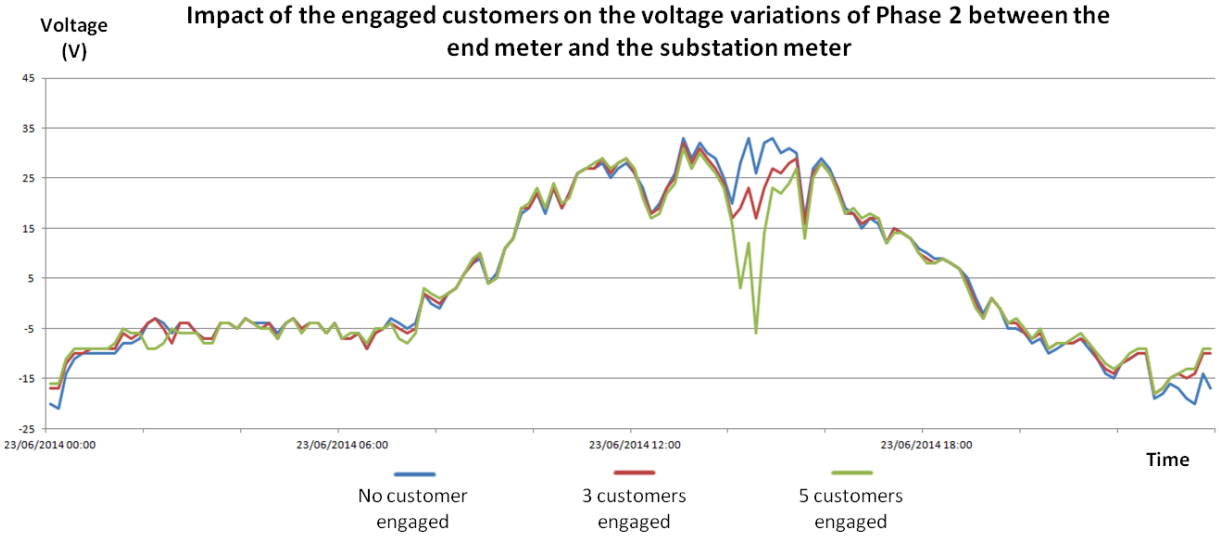
*Impact of engaged customers*

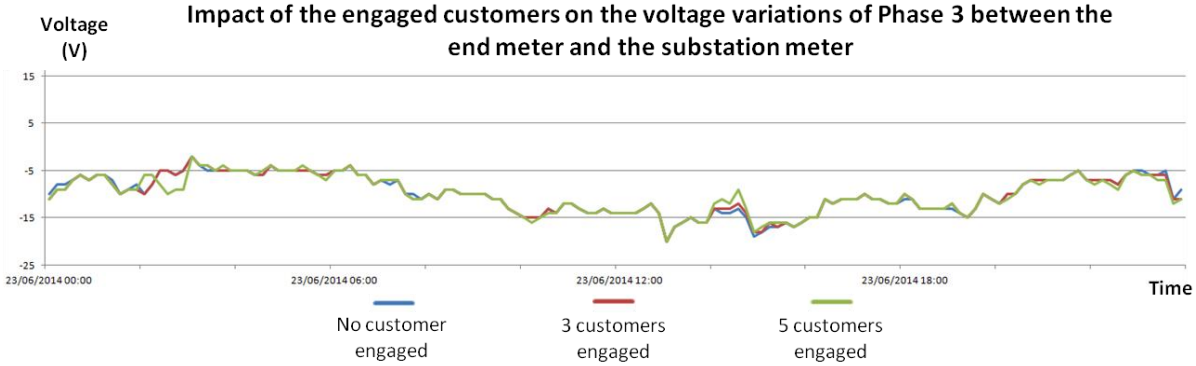
In this section, we will take the study case that challenges the grid the most (production multiplied by six) and change the load of some consumers in order to replicate the presence of engaged customers (using the impact of engaged customers estimated in Appendix II). This will allow us to evaluate the number of engaged customers necessary to alleviate the constraints created by a very high penetration of PV production.

As all of the known production was connected to phase 2, we will only modify the load of consumers connected to this phase. There are eight one-phase customers equipped with a LINKY meter and connected to phase 2 of the feeder 06033001593 of the Colombie substation, five of these customers have an electric water heater and could in theory be incentivised to shift their load to the afternoon.

We ran the model in three different situations: no customers engaged, three customers engaged and five customers engaged.






The impact of the load shift is quite clear on the voltage curve with a fairly large drop in the voltage of phase 2 during the 14:00-16:00 period. Of course, voltage on the other two phases goes up to compensate.

These results were obtained on a feeder to which the equivalent of twenty-four (four times six) producers are connected. The results of the simulations show that having three customers with an electric water heater shifting their load is sufficient to reduce the voltage increase by 10V for around one hour while having five of those customers can allow you to negate any increase in voltage for the same duration. However, the voltage increase lasts for several hours in total so more customers would be needed to compensate the production during the peak production period (10:00-16:00).

In the end, this leads us to estimate that between 18 and 30 engaged customers with an electric water heater would be needed to balance the twenty four producers. This is quite similar to the first guess that was put forward in Appendix II.

*Conclusion*

In this appendix, we made the most of the available model of the low voltage network to try and scale up the results of our experiments. We focused on a specific feeder and started by looking at the impacts an increase in production would have on the different phases. This allowed us to determine when the constraints created by PV production became too difficult to adapt to for a classic network. This was estimated at around 40% of PV penetration for the selected feeder.

We then tried to mitigate the negative effects of the PV production by incentivising customers equipped with an electric water heater to shift part of their load to the afternoon. This led us to confirm two conclusions that were first put forward in Appendix II. The first is that the major part of the customers' impact is felt over an hour long period corresponding to the water heater consumption. The second is that triggering the water heaters does have a large impact on the voltage and could be used as an effective way of limiting the negative impact of PV production on voltage even though it would be extremely difficult to implement at a local level.

In the end, this legitimises the approach of the project which is to engage customers into adopting new consumption patterns in order to move consumption to the PV production period. However, this also highlights the need to trigger customers successively in order to ensure that the whole production period is addressed and not just a couple of hours. This is similar to what is done at a national level where electric water heaters are triggered at different times during the night, but it could prove more difficult to set up at a local level as fewer customers are available. Moreover, it would be useful to complete the system with diversified offers that would engage customers who do not have electric-water heaters. Residential storage with Li-Ion battery would represent an additional solution to move the production to the consumption period rather than the opposite. Such a complex system with such a wide range of offers and incentives may be too difficult to implement at a local level, leading us to think that looking at larger groups of customers (such as MV feeders rather than LV feeders) may be more efficient.

# 3 Assessment of the batteries and inverters experiments

## 3.1 Halfway assessment of the grid storage assets

*The NICE GRID project includes grid **storage assets** as levers to integrate massive PV generation, to operate load shedding and to test **islanding** on a commercial district. There are four grid **storage assets**[2], operated by the French Distribution System Operator (DSO) ERDF[3], and installed at different location of the distribution grid: primary substation, secondary substation, low voltage grid[4]. According to its location, each **storage asset** is able to perform one, two or three of the different NICE GRID use cases.*

*Over the past year, the **storage asset** located at the primary substation of Carros has been installed. This 1 MW / 560 kWh Li-ion based asset is composed of a battery container, a converter container and a transformer, and is supplied through a MV feeder for the main power circuit, and a LV feeder for the auxiliary circuit. Furthermore, it communicates remotely with ERDF's **Regional Control Center**, in charge of monitoring the **storage asset**.*

*Installing such a storage asset required a lot of preparation: site selection, administrative procedures, civil works and tests. It required also a deep risk analysis, in order to assess and implement safety measures.*

*The storage asset created new constraints for ERDF grid management, which is divided between **control** (remote management) and **operation** (on site management). In order to use the **storage asset** efficiently and safely, ERDF had to train controllers and technicians; furthermore new **control and operation** strategies had to be defined.*

*In particular, a **storage asset Human Machine Interface (HMI)** has been developed by ALSTOM GRID[5], in order to monitor remotely the state of the **storage asset**, send charge and discharge schedules, and retrieve potential alarms from the system. Alarms are ranked according to their severity level, and specific treatment is available for each type of alarm.*

*The first results for charge/discharge tests enable the **storage asset** efficiency computation. The auxiliaries, like HVAC[6], which are running 24/24, have to be taken into account in such a computation.*

*This experience gained on the first **storage asset** is now used for the three other ones, which will be installed during autumn 2014.*

*The **storage asset** that operates islanding requires adjustments at the secondary substation: some **islanding** equipment has already been installed and civil works completed. The two **storage assets** located on the LV grid are integrated in containers, which have already been built, and the civil works on site have begun*

[2] This deliverable focuses only on grid storage asset, different from residential storge assets, installed at customer premises (4 kWh / 4.6 kW)
[3] ERDF manages 95% of the French distribution grid, composed of MV (20 kV) and LV (400V) network.
[4] Primary substation is 225 kV / 20 kV station (HV/MV) and secondary substation is 20 kV / 400 V.
[5] Alstom Grid is in charge of three main components related to the storage asset: the supply of the 1 MW power converter, the development of a Human Machine Interface (HMI) and the supply of a Master Control Unit to manage the storage asset
[6] Heat Ventilation Air Conditioning

### 3.1.1 Introduction to the storage assets

*One way to increase the integration of photovoltaic (PV) electricity in distribution grids is to install* ***storage assets*** *at various points of the grid. For this purpose* ***Li-ion batteries*** *supplied by SAFT, as well as* ***battery converters*** *supplied by ALSTOM GRID and SOCOMEC, partners in the project, will be used.*

*Grid* ***storage assets*** *allow the local electricity management optimization, at different levels of the distribution grid. The batteries will be used to control the massive* ***injection of PV generated power*** *into the grid and* ***to shed load*** *at the request*[7] *of the French TSO (RTE). In addition to this, a 250 kW / 600kWh* ***storage asset*** *will be used to test* ***islanding*** *of a district at specific periods.*

- **Storage assets**

The NICE GRID project is testing **grid storage assets** at the following three levels:

- 1 **storage asset** at a primary substation (**HV/MV**): **P**rimary **S**ubstation **B**attery (**PSB**)
- 1 **storage asset** at a secondary substation (**MV/LV**): **S**econdary **S**ubstation **B**attery (**SSB**)
- 2 **storage assets** connected to the **L**ow **V**oltage (**LV**) grid: **L**ow Voltage **G**rid Battery (**LVGB**)

- ***Primary Substation Battery (PSB)***

This **storage asset** was the first to be installed, in **December 2013**. It is located at the "Broc Carros" Primary Substation that supplies the area of Carros and represents around **20 MW** of peak consumption. The site belongs to ERDF, and the **storage asset** is composed of three containers dedicated to the battery, the **Power Converter System (PCS)** and a transformer.

The **storage asset** has a power of **1 MW** and an energy capacity of **560 kWh.**

- ***Secondary substation Battery (SSB)***

This **storage asset** will be installed during **autumn 2014** close to the secondary Substation of "Dock Trachel". This secondary substation supplies a professional area of 12 clients, with around **250 kW**[8] of peak consumption, and **430 $kW_p$** of PV installed capacity. The **PCS** of this **storage asset** will be located in the secondary substation building, whereas the battery container will be located on the car park of a commercial client.

The **storage asset** has a power of **250 kW** and an energy capacity of **600 kWh**

- ***Low Voltage Grid Battery (LVGB)***

[7] ERDF can also shed load, using a similar interface
[8] The battery has a power of 1 MW, the PCS a power of 264 kW : but the power is limited by French regulation on the low voltage grid. Clients can contract up to 250 kW when they are connected to the distribution grid. Here, the storage asset is connected to a dedicated feeder of the secondary substation.

There will be two **storage assets** connected to the low voltage grid at around 400 m of the secondary substation, in order to **maximize the effect of the storage asset on the feeder voltage curve**. These **storage assets** are integrated in a 10 feet container: the **PCS** and the battery modules are in the same container. These containers are located on a client field and a site owned by the municipality. They will be installed during **autumn 2014.**

These **storage assets** have a power of **33 kW** and an energy capacity of **106 kWh**.

- **Use cases associated with storage assets**
  - ***PV integration***

For grid storage, this use case consists in storing PV energy mostly between 12:00 and 16:00, when the PV generation is high. This reduces **grid constraints** (current and voltage). This use case is relevant for **SSB** and **LVGB storage assets.**

For the first one (SSB), the PV excess energy at secondary substation level will be stored. The secondary substation often has an excess of PV energy: a threshold will be chosen. For example, if the chosen threshold for backfeed energy is 100 kW, the **storage asset** will start to charge, as shown in the next figure:

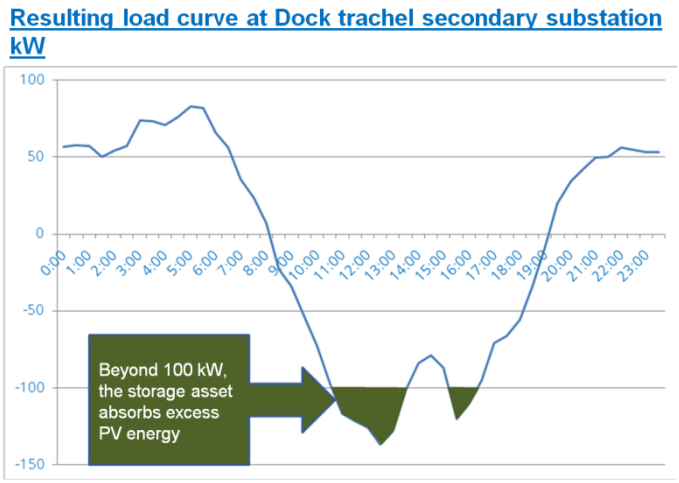



*Figure 29 - Resulting load curve at "Dock Trachel" secondary substation*

For the second ones (LVGB),storage will be installed where the constraints are more likely to be present, 400 m away from the corresponding secondary substation. The storage assets will charge energy between 12:00 and 16:00 on sunny days in order to avoid overvoltage occurrences.

**In both cases, the charge schedule is planned by the Network Battery Aggregator (NBA[9]) and implemented after activation orders from the Network Energy Manager (NEM).**

[9] The NBA is developed by ARMINES and will be operated by ERDF. It is in charge of aggregating the grid batteries in order to respond to the power need request of the NEM

**This PV integration experimentation will take place during summer, and these three storage assets will be used as levers to remove grid constraints due to PV, and thus contribute to PV integration within the distribution grid.**

- ***Load shedding***

This use case is involving the four grid **storage assets**, thus representing **around 1300 kW of aggregated power for discharge**. During cold days in winter, the French TSO RTE[10] is able to send request for load shedding. It usually occurs between 18:00 and 20:00. Grid storage batteries are used as demand response levers, in combination with commercial and residential levers.

**They will discharge between 18:00 and 20:00 during cold days in order to relieve the grid, mostly following an RTE request on a day-ahead basis.** But ERDF can also use these **storage assets** for its own use with the same interface.

**In both cases, the charge schedule is planned by the Network Battery Aggregator (NBA) and implemented after activation orders from the Network Energy Manager (NEM).**

- ***Islanding***

This last use case only concerns the **SSB storage asset**. This storage asset is located close to the secondary substation "Dock Trachel", supplying 12 commercial clients. With 430 $kW_p$ of installed PV capacity and a 600 kWh **storage asset**, it will be possible to disconnect this district for the main grid: this is called **islanding . It consists in disconnecting the district from the main grid during 4 hours and supplying it only with the storage asset and the installed PV generators**. This experimentation will be first done in a scheduled way, and then in an unforeseen way, requiring black start. **Islanding** capabilities will be tested in **spring and autumn 2015**.

- **Synthesis**

| Storage asset | Power | Energy capacity | PV integration | Load shedding | Islanding |
|---|---|---|---|---|---|
| PSB | 1 MW | 560 kWh | | X | |
| SSB | 250 kW | 600 kWh | X | X | X |
| LVGB (x2) | 33 kW | 106 kWh | X | X | |

[10] French : ***R**éseau de **T**ransport de l'**E**lectricité*. RTE is in charge of 100% of the French transmission grid.

### 3.1.2 Characteristics of the Primary Substation Battery (PSB)

*This **1 MW P**rimary **S**ubstation **B**attery **(PSB)** **storage asset** consists of the following elements:*

- *a 1 MW / 560 kWh Li-ion **battery container***
- *a **20 kV feeder** (fuse protection / switch) for connection to the 20 kV switchgear*
- *a 20 kV / 500 V – 1 MVA **power transformer***
- *a 1 MW **Power Converter System (PCS)** including the **PCS** control system for Li-ion battery charging, discharging and monitoring functions*
- ***Associated auxiliary and protection devices**.*

*The 20 kV feeder and the 1 MVA power transformer are installed on the **site of the primary substation of Carros**. The **PCS** and the associated control system are integrated on a **20 feet container**[11]. The Li-ion battery is integrated as well in a **20 feet container**.*

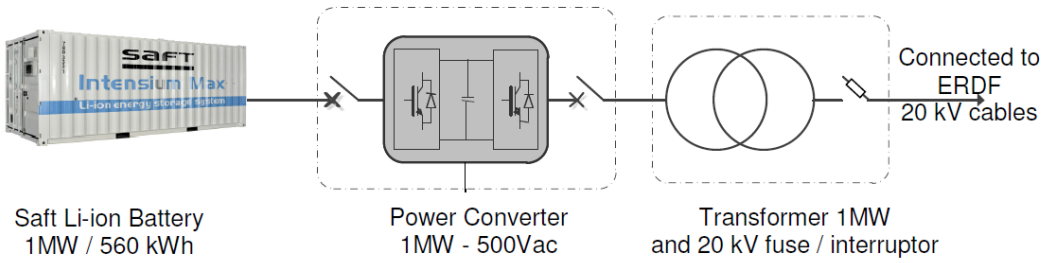



*Figure 30 - Storage asset at the primary substation*

- **Composition**
  - ***Battery container***

*a) Description*

The battery and other equipments to manage the system are installed in a **20 feet container**.

A battery **module** is composed of two parallel strings of 7 Li-Ion **cells** connected in series. An electronic board integrated in the module allows for manage thing cells (balancing, sending data such as end of charge, over temperature, overcharge, over discharge…).

The **B**attery **M**anagement **M**odule **(BMM)** is required to manage and monitor several modules series connected.

[11] Dimensions: 6058 x 2896 x 2438 (mm)

The battery system is composed of **ten** parallel **E**nergy **S**torage **S**ystem Units (**ESSUs**) and one **M**aster **B**attery **M**anagement **M**odule (**MBMM**). The **ESSU** stores and provides energy to the application. Each **ESSU** is made up of 29 **modules** and one **BMM.** The **MBMM (**Master **BMM)** is the top level processing component of the ESSUs. Its main roles are to drive the parallelization of the units during connection/disconnection phases, to perform monitoring at battery level, to communicate with the **PCS**, etc.

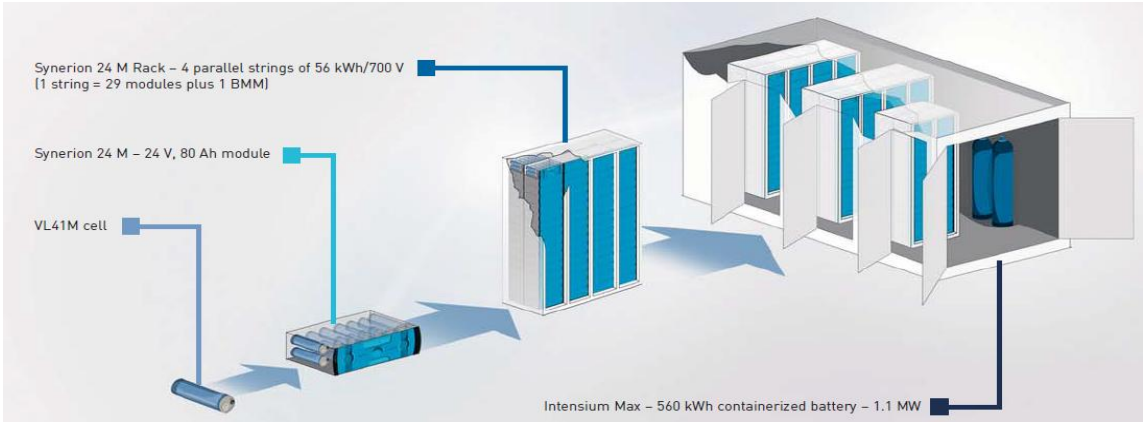

Synerion 24 M Rack – 4 parallel strings of 56 kWh/700 V
(1 string = 29 modules plus 1 BMM)
Synerion 24 M – 24 V, 80 Ah module
VL41M cell
Intensium Max – 560 kWh containerized battery – 1.1 MW

*Figure 31 - Battery container composition*

So as to optimize the yield of the system, the ambient temperature inside the container is regulated. Therefore an **HVAC system** is used for temperature regulation.

A **F**ire **S**uppression **S**ystem (**FSS**) with fire detection and fire suppression is installed inside the container in order to prevent the system from a faulty situation (venting of a cell…).

The **distribution cabinet** is mainly composed of:

- **E**xternal **P**ower **S**upply (**EPS**) distribution: External power supply and the protection of the air conditioning system, lightening (overvoltage protection),
- **S**afe **E**xternal **P**ower **S**upply (**SEPS**) distribution: External power supply and the protections of the FSS, Fans, Lighting system, $230V_{AC}/24V_{DC}$ inverter, lightening (overvoltage protection),
- **$24V_{DC}$ distribution**: $230V_{AC}/24V_{DC}$ inverter to power supply ESSU BMM, MBMM and accessories, emergency pushbuttons line, doors switches (sensors) line, I/O for Air conditioning and Fire Suppression System,
- **MBMM**,
- **Ground fault detector** on battery DC bus,
- **CAN Open bus network**: lightning (overvoltage protection),
- **DC Network**: Lightening (overvoltage protection), manual switch disconnector to isolate the system during the maintenance phases
- **Earth connection**.

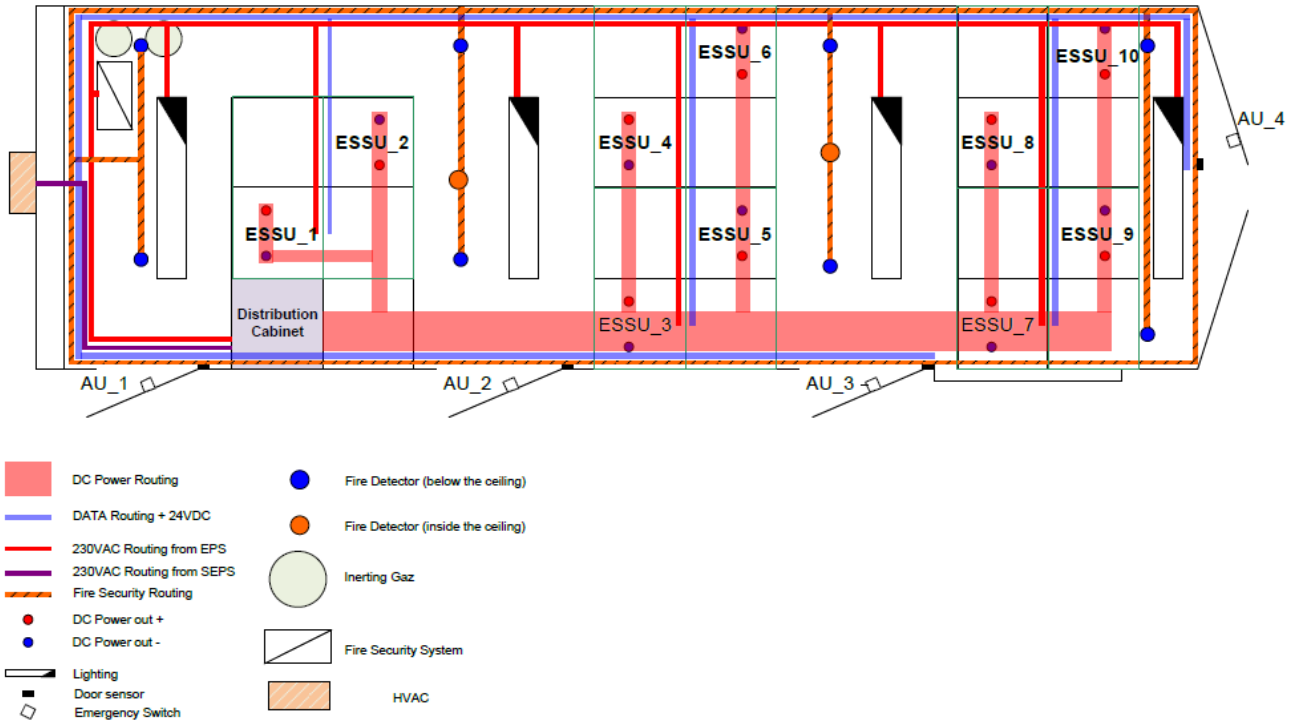



*Figure 32 - Battery container structure*[12]

*b) Single Line Diagram*

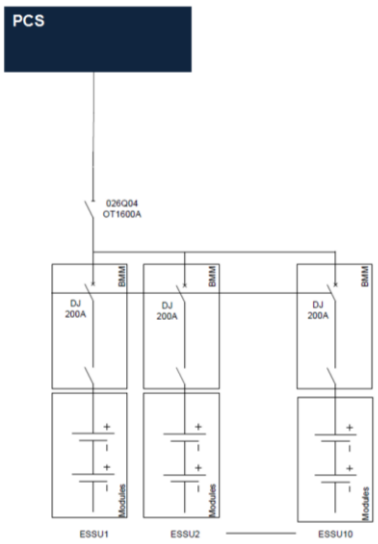



*Figure 33 - Single Line diagram of the battery container*

[12] Source : SAFT

*c) Ancillaries with the main power consumption*

The main consuming ancillary is the **HVAC system**, with a nominal power consumption of **3, 7 kW.**

- ***PCS container***

*a) Description*

The **Power Converter System** (**PCS**) is part of the storage substation. The main functions of the **PCS** are:

- Ensure the **correct energy adequation and transfer** (charging or discharging mode) between the 20 kV network on AC side and the battery system on DC side,
- **Manage any setting point** for load leveling from a remote operator (automatic or manual mode).

The 1 MW **converter**, the associated control system and the cooling, are located in **20 feet container**. Relying on an **I**nsulated-**G**ate **B**ipolar **T**ransistor (**IGBT**[13]**) based 4-quadrant converter system**.

The converter control system communicates and manages the **MBMM**, to assume the proper and secure operation of batteries. All required AC and DC protections are included in the **20 feet container**.

*a) Single Line Diagram*

[13] The insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device primarily used as an electronic switch and in newer devices is noted for combining high efficiency and fast switching.

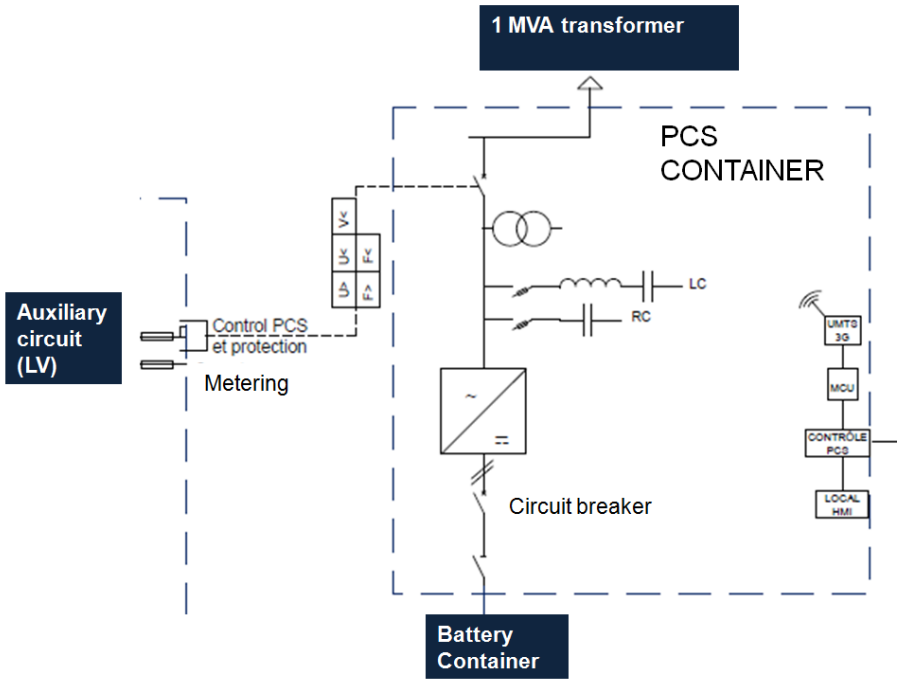



*Figure 34 - Single Line Diagram of the PCS Container*

*b) Ancillary circuit*

The **PCS** has three ancillary circuits:

- A 400 $V_{AC}$ distribution, mainly for **rotating equipments** (pumps and fans)
- A 230 $V_{AC}$ distribution for lightning and **power socket distribution** inside the container
- A 230 $V_{AC}$ UPS (secured) for **control distribution** (HMI…)

*c) Ancillaries with the main power consumption*

The two main consuming ancillaries are:

- The **cooling unit**: It is installed inside the container in front of the LV power and control cubicle. The interface connects the **PCS** and the cooling unit by two pipes. The two pumps represents approximately **1,1 kW** power consumption
- The **shelter and heat exchanger**: An external heat exchanger is required to cool down the cooling water circuit of the **PCS**. It is installed on the roof of the **PCS** container. There are three fans, representing **3x0,74 kW** power consumption

- ***Transformer container***

The **PCS** is connected to the MV grid by three power wires through a MV cell including the **1 MVA power transformer.**

The 20 kV cell is composed of:

- 1 MV protection cell including :
  - disconnector with double earthing switch
  - fuses for power transformer protection
  - current transformers (**CT**) with 2 secondary for **PCS** measurement and ERDF counting
- 1 MV measurement cell including :
  - disconnector with earthing switch
  - fuses for Voltage Transformers (**VT**s)
  - with 2 secondary : 1 for ERDF metering and 1 for **PCS** measurement and protection relay
- A power transformer (1 MVA)
- 1 protection relay for voltage (min and max), frequency and homopolar protection
- **DEIE** device[14]
- A metering device for ERDF: ICE meter[15]

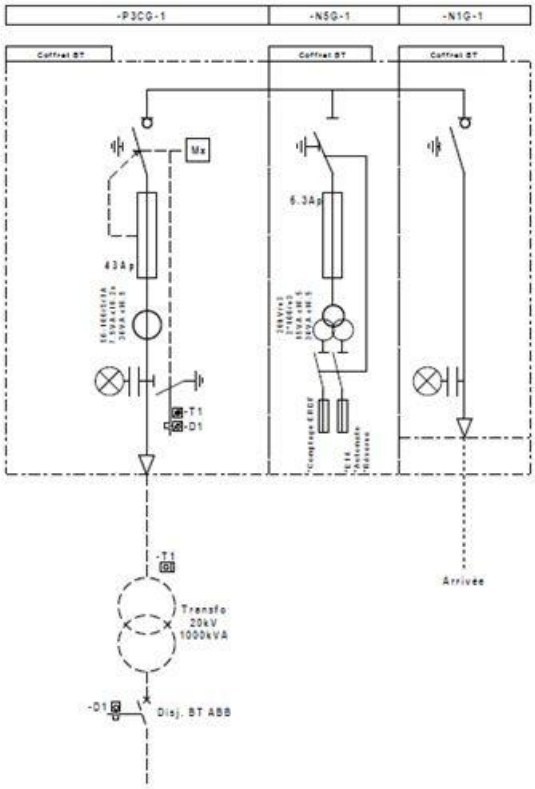



*Figure 35 - Single line diagram of the storage transformer*

[14] The DEIE is used to open remotely the power circuit

[15] This meter is used to measure power consumption of the storage asset (auxiliaries are not taken into account)

- ***Telecom***

The **control system of the PCS** is in charge of managing any remote set-point for load leveling and interact with the SAFT battery **MBMM**, the 1 MVA power transformer and the associated interrupter/fuse, the **M**aster **C**ontrol **U**nit (**MCU**, *see section 5*) and some of the equipment of ERDF 20 kV substation.

The following communication can be mentioned:

- The **PCS and the Battery MBMM** communicates through MODBUS. This allows to manage and control **charge /discharge of the battery, and retrieving alarms.**
- The **PCS and MCU** communicate through an OPC link. The **MCU** hosts the **H**uman **M**achine **I**nterface (**HMI**) described in *section 6*.

ERDF decided to add to this telecom architecture the possibility to order the opening of the power supply circuit (battery and **PCS**) **through its own reliable infrastructure**. The **DEIE** is **able to open the main circuit breaker of the storage asset**. It communicates though RTC with **SIT-R**, ERDF own SCADA for MV feeders and primary substation monitoring, at the **Regional Control Center (ACR).** The **ACR** can open the main circuit breakers remotely through the **DEIE**.

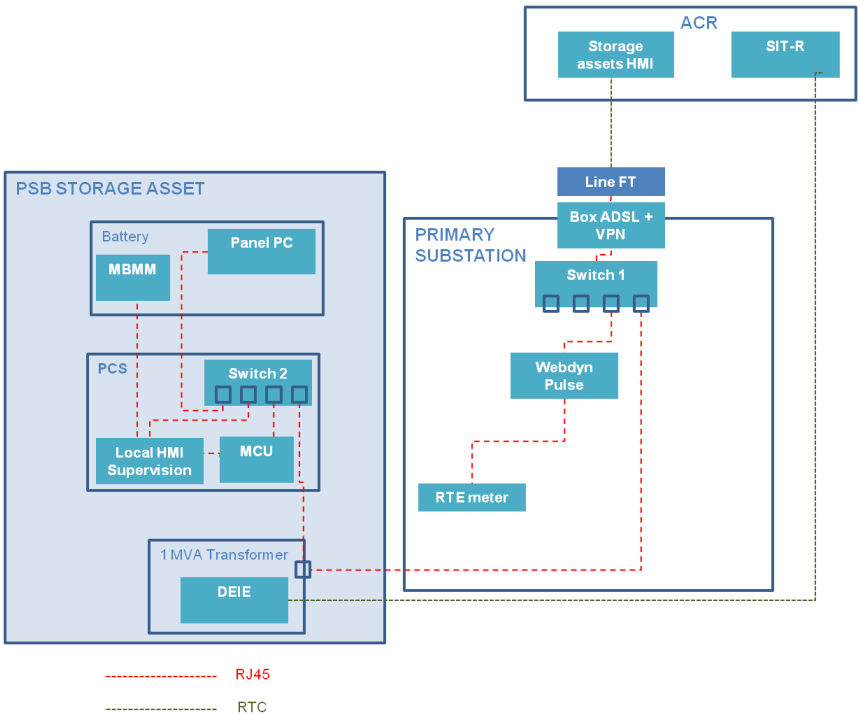



*Figure 36 - Telecom architecture for the PSB storage asset*

- **Grid connection**
  - ***Main power supply***

The 1 MVA transformer of the storage asset is connected to the MV distribution grid through an underground 20kV cable connected to the dedicated 20 kV feeder "SAFT" directly from the 225/20 kV primary substation.
A dedicated meter “ICE” usually used for some MV clients is metering the consumption of the power supply circuit.

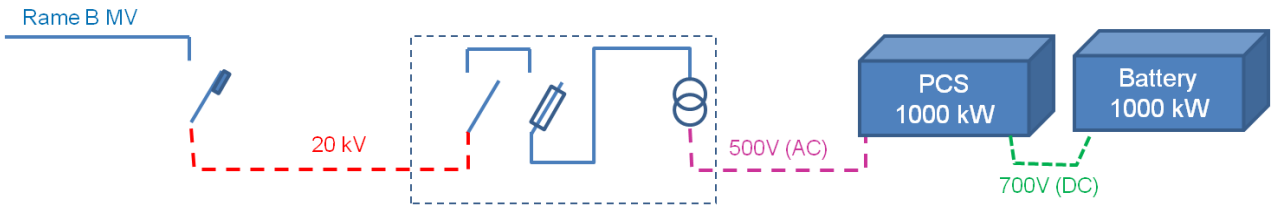



*Figure 37 - MV grid connection of the PSB storage asset*

  - ***Auxiliary power supply***

The **storage asset** also benefits from a LV power supply 36 kVA three-phase type II[16] for supplying the **PCS** and battery auxiliaries.

[16] i.e. meter and breaker at the boundary of property

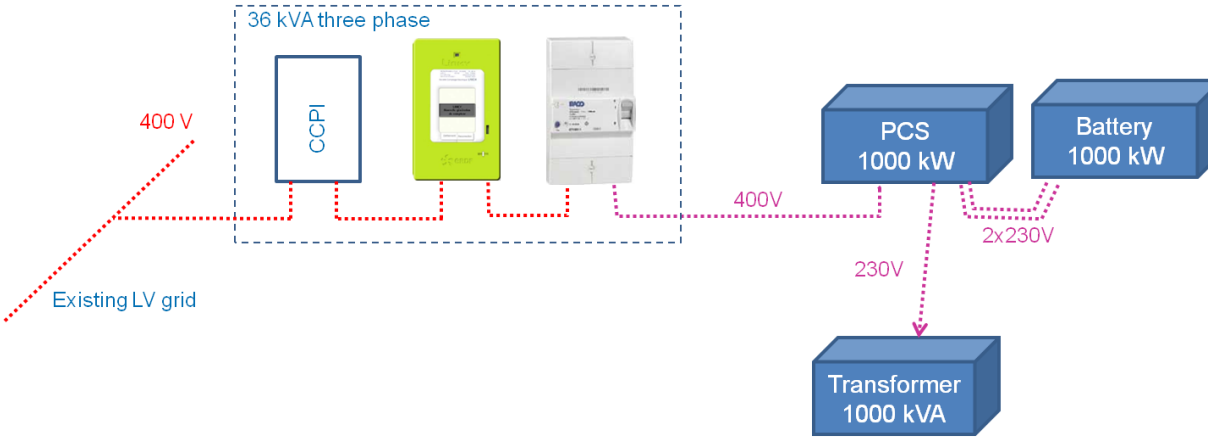



*Figure 38 - Grid connection of the auxiliary supply*

A meter **and a circuit breaker 60 A / 3 Phases** are located at the edge of the perimeter fence substation, as shown in the following picture:

*Figure 39 - Circuit breaker and meter for the auxiliary feeder*

After the circuit breaker, the cables are connected to the GDP of the **PCS**, as shown in the next Single Line Diagram.

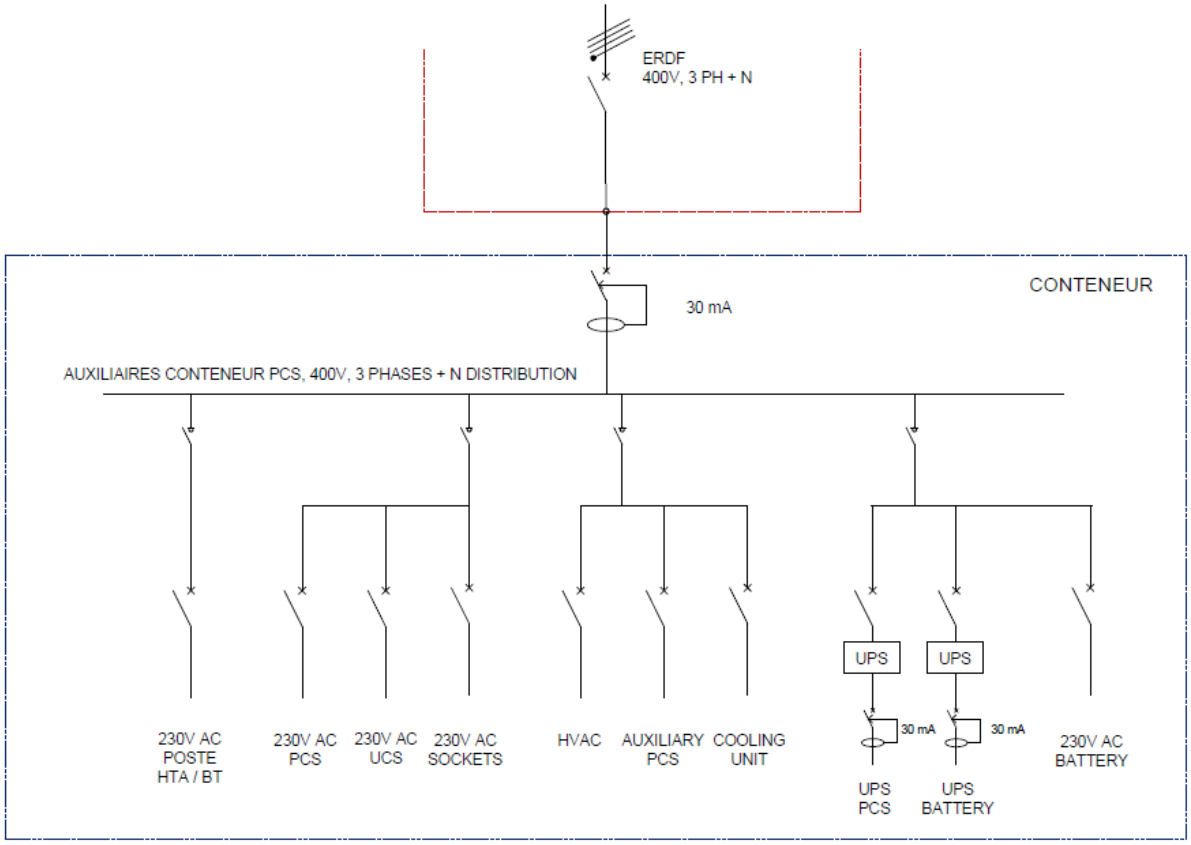



*Figure 40 - Single Line Diagram for the PCS AUXILIAIRIES*

The GDP of the **PCS** is thus supplying the auxiliaries of the **PCS** and the 1 MVA transformer, but also the auxiliaries of the battery container, with two different circuits described above: SEPS (secured) and EPS (standard)

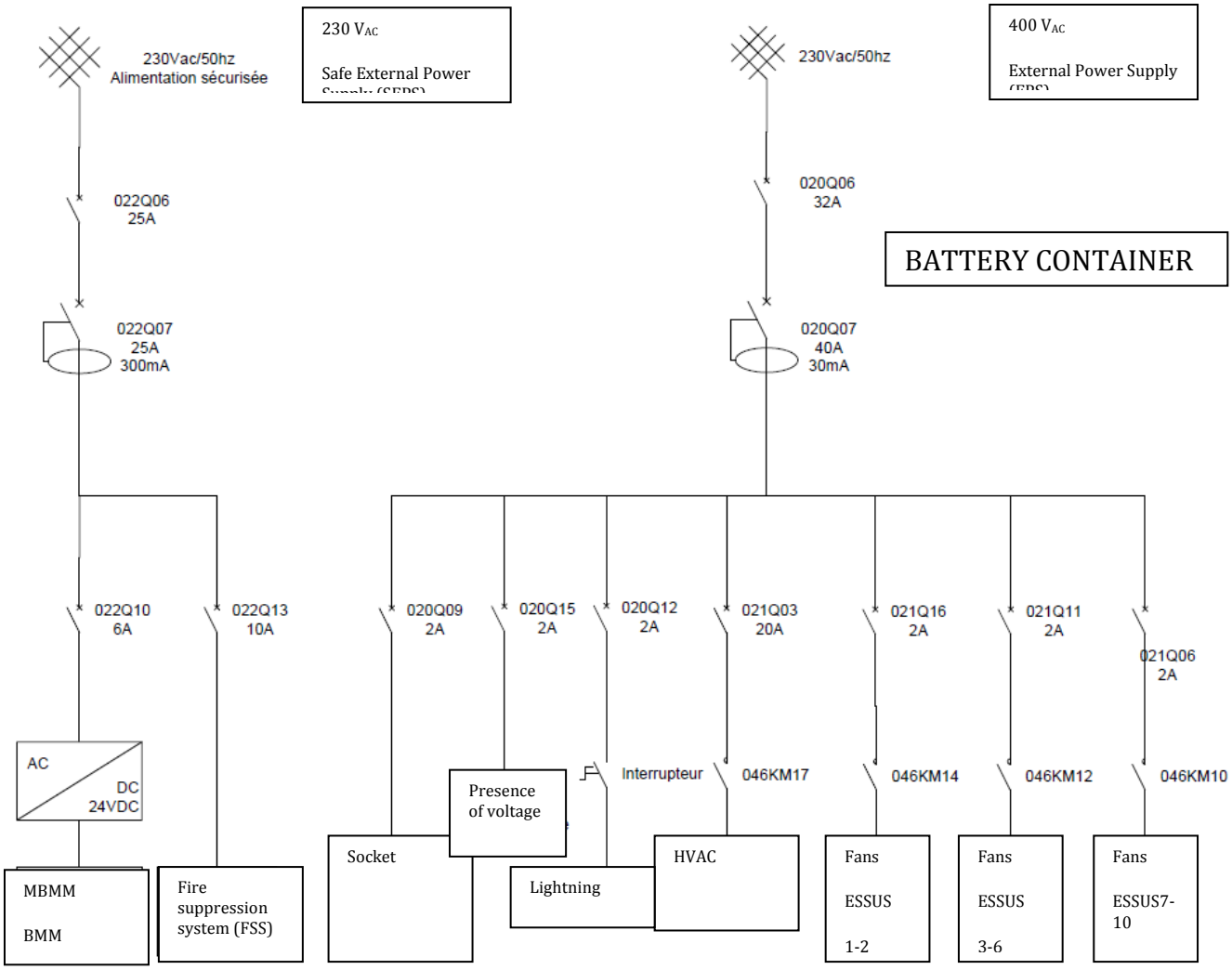



*Figure 41 - Single Line Diagram for the battery container auxiliaries*

### 3.1.3 Installation

*Installation and commissioning of the storage assets require several administrative and testing steps which ERDF had to tackle. The risk analysis is described in section 4.*

- **Site selection**

In order to install such a storage asset and to respect the appropriate safety distance, **a location with a minimum size of 50 m² is necessary, even for the LVGB storage assets**, which could be difficult to find. Regarding the PSB **storage asset**, it has been installed on a field **owned by ERDF**: the storage asset on the primary substation field. For the other storage assets, as described in the last section, it is more difficult because ERDF does not own any sites on the low voltage area.

Another important step is to meet the **architects** of the municipality. Here, the architect of Nice Côte d'Azur (NCA) had to be consulted. For these storage assets, they demanded a trees hedge in front of the storage asset. This step is relevant for sub-urban area. In Carros, the site selection has also to comply with the **flood protection plan**, **fire protection** and **environmental requirements**.

- **DREAL and ICPE Declaration**

Two preliminary administrative steps regarding environment shall be conducted: a declaration to the DREAL, an administrative body representing the Ministry of Ecology, Sustainable Development and Energy at the regional level, and an ICPE declaration.

- ***Declaration to the DREAL***

The **R**egional **D**irectorate for **E**nvironment, **P**lanning and **H**ousing (**DREAL**[17]) represents the only driver at the regional level for the implementation of public policies of the Ministry of Ecology, Sustainable Development and Energy. Under the authority of the regional prefect, DREALs are responsible for developing and implementing government policies on climate change, biodiversity, construction, urban planning, transport infrastructure, energy, security, industrial activities, and pollution prevention.

**A document describing the storage assets and its use cases has been sent to the DREAL Provence Alpes Côte d'Azur in 2013.**

- ***ICPE Declaration***

The regulation of **C**lassified **I**nstallations for the **P**rotection of **E**nvironment (**ICPE**), part of the Environmental Code, aims to establish technical and procedural rules for facilities which could have significant impacts on the site environment or human health of local residents.

It is therefore necessary to establish an inventory of some physical data describing the system (amount of materials with certain characteristics of risks, installed electric power etc. ...)

[17] French : *Direction régionale de l'environnement, de l'aménagement et du logement*

Below certain thresholds for these physical quantities, no ICPE prescription is applicable. There are several regimes: **declaration (D), authorization (A), special authorization (SA)**…

To date, due to the recent appearance on the market of lithium ion batteries, the ICPE regulation is not very clear. However, in the context of a precautionary principle, it was **necessary to make a broad interpretation of the headings of the sections** in order to identify what are the technical and regulatory rules that can apply to the asset.

The analysis revealed that only one section of the ICPE is applicable: it is the **section 2925** "Workshops of batteries". Upon **reaching an electrical power of 50kW**, **a declaration (D) must be done.**
The following table gives an overview of the **inventory** done for the storage asset:

| Item | Application to the storage asset |
|---|---|
| Nature and the maximum quantities of substances, products or materials that will be (or are) used or stored for the activities | No products are stored. They will be brought on site for maintenance |
| Power and capacity of the used machines | 1 MW and 560 kWh |
| Water usage | No water grid connection. Tight container. Retention reservoir available |
| Water evacuation | Tight container. Rain water on the container will be drained by the existing water evacuation system |
| Gas emissions | Not applicable |
| Noise, vibration and smell | Not applicable |
| Waste | In normal conditions, no waste. In case of problem, waste will be contained in retention reservoir and evacuated by a specialized company |
| Safety | Retention reservoir for each battery rack<br>Safety instruction displayed for operators<br>Automatic monitoring of equipments<br>(See section 4) |

**ICPE declarations have only been sent for the PSB and SSB storage asset, as they have an electrical power above 50 kW. They have been submitted respectively in autumn 2013 and spring 2014, and have been accepted without any restriction or comment.**

- ## Building permit

Several entities have been consulted. ERDF, as legal person, has to submit a **building permit request** signed by an architect.

The building permit request is composed of eight documents:

- PC1: Site plan

- PC2: Ground plan
- PC3: Sectional drawings
- PC4: Notice describing the land and presenting the project
- PC5: Facades and roofs drawings
- PC6: Graphic material for assessing the integration of the construction project in its environment
- PC7 and 8: Photographs to locate the field in the near and distant environment

These documents have been sent in 10 copies to the Carros municipality. This large amount of copies corresponds to the large number of public stakeholders which have to be consulted, including the firefighting prevention department. Today, two building permits have been approved and two are still under discussion. As lithium ion based batteries are a new technology (at this scale), it brought a lot a questions and discussions about their implementation at this scale in suburban areas like Carros. The two remaining building permit requests were approved in August 2014.

- **Civil works**

Civil works for the PSB storage asset consisted in four main tasks:

- building the prefabricated hosting for the 1 MVA transformer

- installing a 2 m high fence around the site

- Installing concrete blocks to support the battery and **PCS** containers

- installing pipe sleeves and cables for grid connection

These civil works were completed in autumn 2014, and the following pictures show the different phases of installation

*Figure 42 - Civil works for the PSB storage asset*

- **Installation**

Installation of the battery and **PCS** containers was done by November 2013, as shown in the following pictures:

*Figure 43 - Installation phase for the PSB storage asset*

- **Testing phase**

After the installation of the three elements of the storage assets, tests have been conducted **between December 2013 and March 2014**. During this test phase, the storage asset was operated by SAFT (battery container) and ALSTOM GRID (converter and transformer)

The following list gives an **overview of the different tests**:

- Check installation conditions
- Check lightning chock between **PCS** and battery
- Check communication MBMM – PCS
- Check FSS of the battery
- Check status fire
- Check HVAC of the battery (and if it stops while the doors are open)
- Check emergency stop
- Check earth continuity
- Check insulation resistance
- Check EMC levels in the containers (battery + **PCS**) once on the site (near the primary substation)
- Check earth continuity (Battery-**PCS**)
- Check the adjustment of measures for insulation resistance (100 kΩ)
- System response when measured insulation resistance is too low
- Check voltage at the end of charging (<=818 V)
- Check voltage at the end of discharging (>=609 V)
- Fallback position if loss maximum current value from the MBMM
- Check maximum current (<=505 A)
- Complete charge with all ESSUs
- Complete discharge with all ESSUs
- Complete charge with only one ESSU
- Complete discharge with only one ESSU
- Justification for the choice of the strategy of connecting ESSU and test
- Disconnecting an operating ESSU operating then reconnecting it after "creation" of a significant imbalance (e.g. discharging highly an ESSU)
- Stop the air conditioning and full charge / discharge (if possible, if the system allows)
- Check of all the orders to the system
- Order inconsistent instruction if possible
- Check of all the retrieved variables during all the tests
- Check of fallback position in case of communication loss between battery and **PCS**
- Check temperature regulation in the container
- Check fallback position in case of loss of battery auxiliary supply
- Check fallback position in case of loss of **PCS** auxiliary supply
- Check that MBMM alarms are taken into account in the **PCS**

## The four most important tests for ERDF are the following:

**(1) Loss of the MV supply (alarm level 5)**
**(2) Loss of the LV (auxiliaries) supply (alarm level 5)**
**(3) Opening the DEIE in case of emergency (alarm level 3)**
**(4) Communication loss between ACR and MCU (alarm level 5)**

The **final tests reports** were submitted to ERDF on **March 19th 2014.**

### 3.1.4 Risk analysis

*ERDF had to conduct a deep risk analysis of the PSB storage asset, based on internal SAFT analysis and exchanges with its **control and operation** teams, as well as with the fire-fighters. This section summarises the resulting analysis that described the main internal and external risks associated with the **storage asset**, and the measures implemented to mitigate them.*

- **Internal risks**

**Internal risks** are risks proper to the battery and its components. According to SAFT, events related to the use of lithium ion batteries are the following:

- **Fire**
- **Evolution of toxic gases** (carbon monoxide CO and hydrogen fluoride HF): A complete combustion would lead to the release of 3 $m^3$ of gas per kWh installed. This gas would be released into the container, which would be able to contain a few $m^3$ if combustion was incomplete. Larger amount of gas would be discharged to the outside through a **safety valve**. Other gaseous substances can also be released in small quantities from plastics (polypropylene) and other cable insulation material (PVC), electronic cards, but these are not specific to the use of a lithium ion battery.
- **Cut-through** (presence of voltage on an accessible area normally not under tension)
- **Evolution of liquids**: In terms of liquid effluent, in normal operation, the system of energy storage itself generates no liquid discharge. Under fault conditions, leading to a degradation of the storage system, there is no liquid waste.

- **External risks**

These risks are associated with the external environment:

- **Cataclysms**: Earthquakes, hurricanes, volcanoes, floods, dam failures, falling aircraft. Storage is located in an area not subject to these risks. Even if one of these major events was to cause the ruin of the storage system, the loss of the system would only represent a small fraction of the total damage of the disaster.
- **Lightning**
- **Soil quality**
- **Malicious act**
- **Bushfire**
- **Road accident**

- **Implemented measures**

  - ***Fire***

Each container is equipped with a **system for detecting flames**, **heat and smoke** as well as sprinklers when needed. If for some reason the cells had to climb to a temperature above 150°C for over 15 minutes, the fire protection system would operate by releasing nitrogen in the container.

*Figure 44 - Fire Suppression System (FSS)*

  - ***Evolution of liquids***

In case of fire, firefighters centre has received the information **to exclusively use non-conductive fluid such as $CO_2$** when they intervene. They will also set a "**water curtain**" to protect adjacent objects.

Furthermore, **retention** is integrated to each rack with a capacity of up to 100% of the total volume of electrolyte in all the elements of the cabinet.

  - ***Container access***

ERDF surrounded each **storage asset** by a fence located at a **sufficient distance** to open the side doors and allow longitudinal and unrestricted access to the inside of a container on foot. The idea is to restrict the access to authorized staff by limiting the ground surface.

Battery is **not releasing hydrogen**; paragraph 2.1 of section 2925 of the ICPE on minimum distances from the boundaries of ownership **does not apply**. (Voir section 3.2)

  - ***Site selection***

Storage asset is located **outside of any volcanic and highly windy area** to limit the amount of dust which may cause short circuits in all electrical installations.

To prevent the deformation of the container and keep it perfectly sealed, storage is located **on stable ground**.

  - ***Prevention against electrical risks***

The PSB **storage asset** has two separate electrical power supplies:

- **Medium Voltage** (MV) supply (20 kV) from the primary substation
- **Low Voltage** (LV) supply (400V) from the LV network passing through the adjacent street.

It was decided to connect the battery **on a dedicated MV feeder** to ensure the presence of a reliable mean of disjunction and remote monitoring by the **Regional Control Center (ACR)** of Toulon.

This **dedicated circuit breaker** is redundant with:

- the MV switch upstream from the 20 kV transformer
- ALSTOM's main circuit breaker installed at the transformer secondary circuit associated with the inverter.
- Main DC circuit breaker installed in conversion output AC / DC
- DC circuit breakers 700 $V_{DC}$ input of each ESSU
- The "normally open" **contactors** at the top of each battery module

The MV feeder is coupled to an anti-islanding protection in line with the French regulation thresholds.

The key element relating to electrical safety is that the 700 $V_{DC}$ **contactors** are **"normally open",** i.e. they must receive an external power supply to remain closed.

Consequently, any cut on the auxiliary table has the effect of instantly opening the **contactors** and interrupting the power supply in all individual cells.

**These multiple barriers on the main circuit, validated by the various project stakeholders, seem sufficient to ensure the opening of the circuit if necessary. Moreover, according to SAFT, the absence of current in cells guarantees ERDF against the risk of fire.**

In addition, a LV supply (400V - 36 kVA) is provided for supplying the auxiliaries and HMI tool for local control of the inverter. This device is coupled to a **UPS inverter** type to ensure the continued operation of the supervision of the same set in case of power outage on the LV grid.

An additional **emergency stop button** of the battery is placed **outside the container**: the use of this emergency stop is restricted to agents working on the local battery in the event they are faced with an accidental situation uncontrolled by the remote monitoring station.

- ***Malicious act***

An **exterior fence** with access restricted to authorized staff is installed. Furthermore, the container is locked.

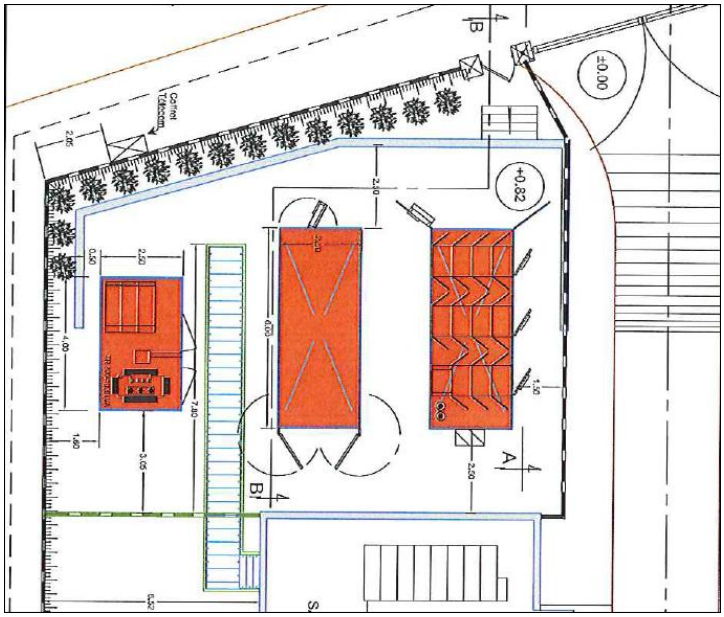



*Figure 45 - Exterior fence*

- ***Bushfire***

The fenced area has no shrub or plant likely to spread a brush fire.

*Figure 46 - Fenced area*

- ***Road accident***

The **closeness to the road** could cause an **external risk** as a vehicle could hit the container and cause a perforation (the container would not be airtight anymore). The fire suppression system (FSS) would then lose its effectiveness as the perforation of the container would allow the presence of oxygen.
The container is installed on a plot:

- elevated relatively to the adjacent roadway
- separated from the road by a concrete gutter (80cm deep and 60cm wide)
- 4m away from the boundary of ownership
- Enclosed by a wire fence 2.3m high.

**Given the fact that this location of Carros has never experienced this type of accident and the street is not busy, the risk is considered very unlikely to occur.**

- ***Lightning***

This risk is prevented by the implemented **anti-lightning system**:

- Direct protection (**primary protection**): device capturing lightning current, low impedance grounding…
- protection against indirect effects (**secondary protection**), which prevents the risk of malfunctions due to surges, through the implementation of various measures (lightning arrestors, earth connections)

The entire storage area is connected with neutral earth ground 1 Ω and interconnected earths: **no identified risk.**

- ***Fire of a building or facility nearby***

To remove the risk of a domino effect following a fire close to the container, SAFT recommends that it should be at a distance of 9 m such that the radiation will be less than 8 kW / m².

This recommendation is not feasible on the site but it is considered that the 3 m that separate the battery from the next building (primary substation building) and the PCS container are sufficient, given the very low fire risk linked to an intrinsic defect in the battery, and the risk from bushfire or motor vehicle collision.

- ***Firefighters***

In case of fire, firefighters receive the information to **use only $CO_2$ in case of intervention**.
Specific training has been provided on site by the manufacturer SAFT. They will set a "**water curtain**" to protect the adjacent building.
In case of a firefighter intervention, ERDF would have previously:

- **Opened the MV feeder** supplying the storage asset at the primary substation
- **Pushed the emergency stop button located on the property line** (redundant with the FSS system which opens the 10 **contactors**)
- **Cut the LV auxiliary circuit breaker 36 kVA** (manually on site)

- ***Periodic inspection***

**Periodic visits** are planned; they include the verification of the following: security system, fire extinguishers, electrical, earthing, ventilation, and air conditioning.

### *3.1.5 Control and operation principles*

*Within ERDF, the primary substation equipments are managed through two entities:*

- *The **control** **team**, based at the **Regional Control Center (ACR)**, is in charge of controlling remotely the MV grid, this includes namely the primary substations and renewable generators connected to the MV grid.*
- *The **operation** **team**, called **AMEPS (Agency for Maintenance and Operation of Primary Substation**), is in charge of **operation** and maintenance for primary substations. The technicians intervene on site, 24/24 and 7/7.*

*For the distinction between **control and operation within ERDF**, see the glossary.*

*These two teams had to be trained to the new equipments, and ERDF implemented some adjustments to comply with its established **control** and **operation** rules, and to ensure more safety and reliability.*

- **Adjustments proposed by ERDF**

As a client of the storage asset, ERDF demanded several adjustments in order to ensure a safe operation. These adjustments are listed below:

- ***Possibility to open remotely the main circuit breaker of the PCS through a proprietary ERDF technology.***

The **D**evice for **E**xchanging **O**perational **I**nformation (**DEIE**) is the mean to automate the exchange of information and control renewable energy generators connected to the Medium Voltage grid. It communicates with the **Regional Control Center (ACR)** through an ERDF protocol called SIT-R. The **DEIE** makes it possible to remotely open the main circuit breaker of the **PCS**

*Figure 47 - Device for Exchanging Operational Information (DEIE)*

#### *3.1.5.1.1 Installation of an emergency stop push button reachable from outside*

*Figure 48 - Localisation of the emergency stop push button*

An *emergency stop* push button is located outside the fenced area in a cabinet (which can be opened with a triangular key). **It opens the DC circuit breakers of the battery**.

- **Installation of terminal covers inside the PCS container**

ERDF installed covers on terminal under voltage within the **PCS** to prevent electrical risks

- **Update of the grounding system** to comply with the rules of access to the network established by the French standard NF C18-510

## Control principles

The **Regional Control Centre (ACR)** based in Toulon is responsible for **controlling** the MV voltage grid. It is operational **24/24 and 7/7.**
It has a dedicated **storage asset HMI** (see next section) in order to monitor and control the storage asset. This was installed during the test phase in order to collect feedback from the grid controllers and optimise it.
The **ACR** is able to

- **Send charge and discharge schedules** to the battery
- **Remotely open the main circuit breaker** of the storage asset
- **Retrieve the alarms of the PCS (**The **PCS** deals with all alarms from the battery or the **PCS**)
- **Gather the operational data of the storage asset** (state of charge…)

Furthermore, the connection between the **ACR** and the storage asset is **tested every minute** (adjustable parameter). In case of no response from the storage system, a level 3 alarm is triggered, the battery stops and the grid controller uses the **DEIE** to ensure the opening of the main power circuit.
The following **control** strategy was decided: **being able to ensure safety 24/24 and doing troubleshooting only during workable hours**.

**ACR** can call on the **operation teams which can then intervene on site**.

*Figure 49 - Regional Control Centre*

## Operation principles

The following **operation** strategy was decided: **being able to ensure safety 24/24 and doing troubleshooting only during workable hours**.

ERDF wrote and displayed instructions on site for **operation** teams (*see appendix 3*)

The training strategy was to form the whole team to ensure the safety, and to select a few people that were trained more deeply if possible with the technicians from SAFT or ALSTOM.

ERDF **operation** teams **can access the inside of the fenced area and the containers**, so they have been trained to the existing risks and to the related emergency measures.
The slow kinetic of a fire enables evacuation of the hazardous area by ERDF staff
To prevent the risks associated with maintenance and troubleshooting, the following measures are implemented:

- Only trained and certified operators intervene on the containers and cabinets
- All metal parts are grounded with annual audit as for other ERDF facilities
- No smoking within the fenced area

### *3.1.6 Communication and Human Machine Interface (HMI)*

*The design of an appropriate Human Machine Interface (HMI) for the storage asset has been an iterative work involving Alstom Grid, SAFT and ERDF. This **storage asset HMI** is available at the **ACR**, in order to display the state of the storage asset, including the possible alarms.*

*There are two versions of the HMI:*

- *A "black" one, which is simplified and allows the technicians of the **ACR** to monitor the asset with the charge and discharge schedules for active power and the display of the alarms*
- *A "blue" one, which is more specific to the **PCS**. It is possible to connect with the **PCS**, to have more information regarding the **PCS** alarms. It is possible to achieve a better diagnostic and to send charge and discharge schedule with reactive and active power*

*The "black" HMI is described in this section. This **storage asset HMI** will be extended for the other grid batteries. Buttons are already present, as shown in the following figure:*

*Figure 50 – Selection table*

- **Master Control Unit (MCU)**

The **Master Control Unit (MCU)** is a computer responsible for monitoring the storage asset. The selected architecture is presented on the next figure. The storage asset is monitored though a remote HMI on the NBA server. There is no connection between the NEM and the **MCU** for the moment. The storage asset is still controlled manually through the **ACR**.

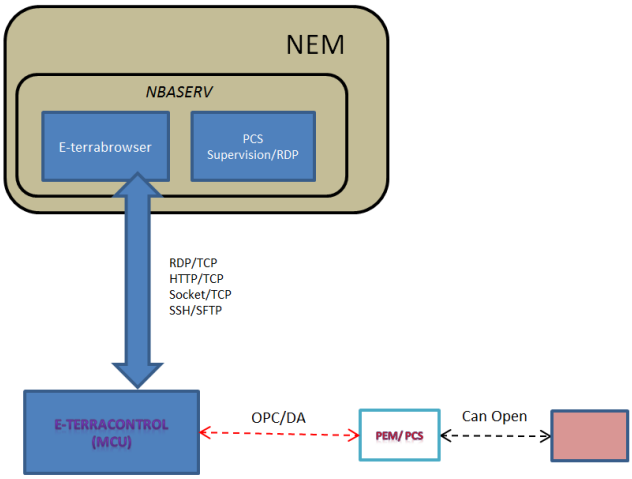



*Figure 51 - Architecture*

The function of the **MCU** regarding the storage asset is:

1. The **storage asset HMI** from the **MCU** makes it possible to send a **charge / discharge schedule** of active power for the storage asset for the next 24 hours at a 30 minutes time step
2. The **MCU** gathers the schedule from the HMI e-terrabrowser and sends the **corresponding instructions (set points)** to the battery through the **PCS**, using the OPC protocol
3. **Operating data of the storage asset** are sent to the **MCU** via the OPC protocol. These data can be displayed though the HMI of the **MCU**
4. The **controllers in the ACR** can monitor **in real time** the operation of **PCS**/Battery, in particular:
    a. Displaying **alarms**
    b. Monitoring the **battery SOC**
    c. Monitoring the **system state**
    d. Controlling the operating modes of the system : start, stop, standby

- ## Presentation of the interface

The **storage asset HMI** is displayed on a **dedicated** computer at **ACR**. It must be simple to use, and there should not be too many alarm sounds, in order for the controllers to work properly.

The main display from the HMI is presented on the next figure. There are several boxes for:

- The battery state
- The **PCS** state
- The instructions
- The load curve

- The alarm list

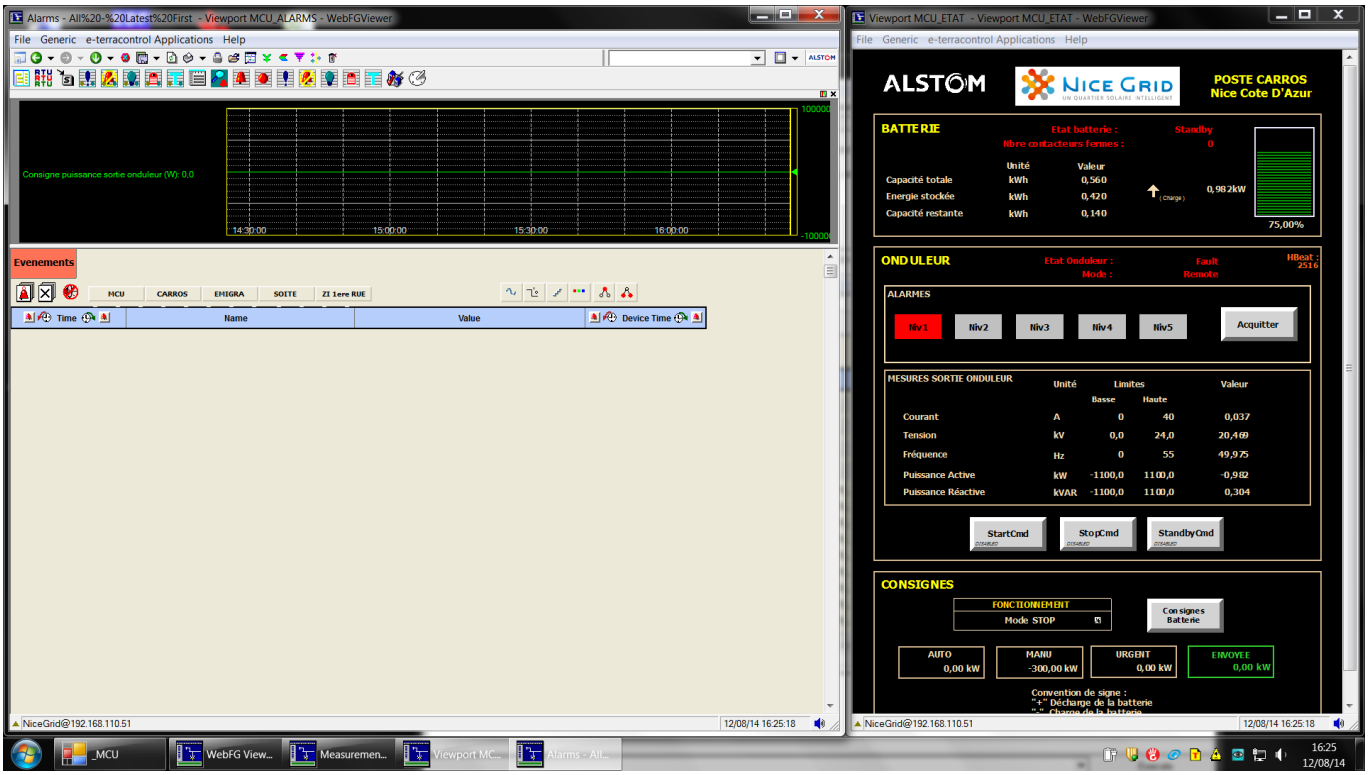



*Figure 52 - Main screen of the storage HMI*

- ***Battery box***

The following information associated with the battery state is displayed in the **battery box**:

- **Total capacity** (560 kWh)
- **Stored energy** (in kWh)
- **Remaining capacity** (in kWh)
- **Charging/discharging power** (in kW). Positive values are associated with discharge
- **Battery State of charge (SOC)** (in %) with a visual display
- **Battery status**: Nominal / Standby / Stopped…
- Number of closed **contactors**

*Figure 53 - Battery box within the storage asset HMI*

- ***PCS box***

The following information associated with the **PCS** state is displayed in the **PCS box**:

- State of the **PCS** (fault/standby/stopped…)
- Monitoring mode (local/remote)
- Alarms and alarms acknowledgment
- Measured outputs:
  - Current (A)
  - Voltage (kV)
  - Frequency (Hz)
  - Active power (kW)
  - Reactive power (kW)

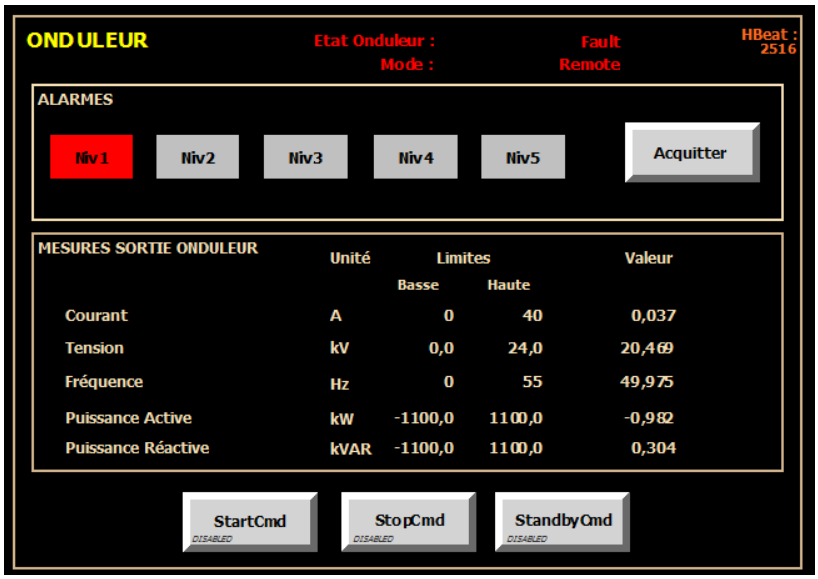



*Figure 54 – PCS box of the storage asset HMI*

- ***Instruction box***

The instruction box allows for sending battery schedules. It is represented in the figure below:

-


*Figure 55 - Instruction box of the storage asset HMI*

- ***Output power box***

*Figure 56 - Output power box of the storage asset HMI*

The output power box provides the load curve of the storage asset, as shown in the figure above

- ***Event box***

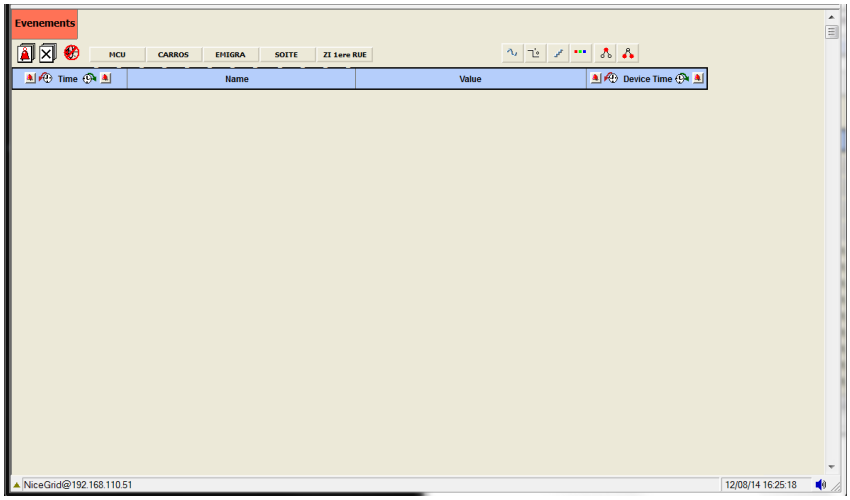



*Figure 57 - Event Box of the Storage asset HMI*

The event box of the **storage asset HMI** provides the list of all the occurred events. Some of them are linked with alarms. Alarms have five levels of severity (level 5 is the highest level)

Battery and **PCS** alarms are managed automatically by the **PCS**. In case of an alarm, the **PCS** and the battery will be set in safety mode (power circuit opened). The only role of the **ACR** controller outside workable hours in case of an alarm is to check that the **PCS** is stopped. If it is not the case, the controller opens the power circuit though the **DEIE** system (reliable and in operation for renewable energy generators).

### 3.1.7 First results of the PSB

*The storage asset at the primary substation is now under operation and ERDF gathered some first results. This section describes the first results with some charge and discharge schedules, and computes the efficiency of the system.*

*This efficiency will be computed in the final deliverable.*

### 3.1.8 Overview of the status of the other storage assets

*The PSB storage asset is operational, and the three additional grid batteries will be installed during autumn 2014. The process is quite similar, as ERDF used the* ***experience gained on the PSB installation****. This section aims at describing the differences with the PSB as well as the actual status of the three other grid storage asset: the* ***secondary substation battery*** *(SSB) and the two* ***low voltage grid batteries*** *(LVGB)*

- **Comparison between the PSB and the other batteries**

The three other grid storage assets, are low voltage storage assets, i.e. they are connected to the LV distribution grid (400 V). This has the following consequences:

- There is no need for a dedicated ancillary supply. The two LVGB have an **ancillary circuit derived from the power circuit**, and the SSB has an **ancillary circuit derived from the General Distribution Panel (GDP) of the secondary substation**
- Instead of a **DEIE**, which is normally used for MV generators, **R**emote **S**witch **I**nterfaces (**ITI**) are used. They are normally used on the MV voltage to remotely reconfigure the grid: the use of ITI on the low voltage grid to remotely open the circuit breaker of the storage assets in case of an emergency is **an innovation for ERDF.**
- The operators are not from **AMEPS** but from the **Grid Operation Agency (AREX)**. Although the grid storage assets are located on the LV grid, they will still be controlled by the **ACR** (which normally only controls the MV grid)

Here are the further differences with the PSB:

- **PCS** are supplied by **SOCOMEC**, using 33 kVA standard units.
- The three grid storage assets are involved in **PV integration**, as they are located close to PV generators

Here are the similarities with the PSB:

- The same **storage asset HMI** will be used at **ACR**
- **ACR** can open remotely the power supply through a proper ERDF system
- The **control and operation** strategy will be the same. Regarding **operation** for example, all the technicians will be able to set the storage asset in safety, but only two technicians will be able to troubleshooting in workable hours.

- **Secondary Substation Battery (SSB)**

Here are the **main features** of the SSB storage asset:

- The battery container is similar to the PSB battery container, but it has more capacity: **600 kWh**. It is located on the parking of "LA POSTE[18]", separated by a road from the secondary substation
- The **Power Conversion Systems** are located **within the secondary substation building**. 4 modules of 66 kVA are combined in order to reach **250 kW**[19] of nominal power, i.e. the maximum power for a client en the LV grid.
- The storage asset is connected to a **direct LV feeder**, with **a SME meter**
- Auxiliary circuit is supplied **by the GDP of the secondary substation**

Here is the status of the SSB installation by **September 2014**:

- The battery container is **ready to be installed**
- The General Distribution Panel (GDP) of the **PCS** **are under construction**
- Civil works are under process in the secondary substation, in order to install the **PCS** and auxiliary cabinets
- The **penetration sleeves** under the roadway between the **PCS** and the battery container have been realised.
- The parallel circuit breaker (PCB), which will disconnect the district from the main grid during **islanding** operation has been installed, and integrated in a "parallel cabinet". This "coupling cabinet", adjacent to the GDP of the primary substation, is shown on the picture below:

*Figure 58 - Parallel cabinet in the "Dock Trachel" secondary substation*

- **Low Voltage Grid Battery (LVGB)**

Here are the **main features** of the LVGB storage asset:

- The battery and the **PCS** are integrated in the same **10 feet container**

[18] French Post company

[19] 250 kW is the maximum power to be connected to the LV grid.

- There are two ESSUs per container, reaching **106 kWh** of energy capacity
- Each container has a 33 kW **PCS**
- Each container is connected to the LV grid and metered with a **SME meter**
- Ancillary circuit and power circuit are supplied **by the same grid connection**

Here is the status of the SSB installation by **September 2014**:

- The first container which will be tested at the Renardières research centre is built, as shown in the next pictures. The two other ones which will be installed in Carros will be ready by the beginning and the end of October

*Figure 59 - Built container at SOCOMEC factory in Benfeld*

- Civil works are ongoing. For one asset, the grid connection is already built, as shown in the picture below:

*Figure 60 - Grid connection for the LVGB near Cailletiers secondary substation*

### 3.1.9 Conclusion

The installation and commissioning of the storage asset is a new process at ERDF, and requires a lot of different steps, on the administrative, security and training side. The experience gained on the PSB storage asset will be used to install the further three grid storage assets. These assets will be used for the next winter experimentation (December 2014).

One of the main lessons learned is the importance of safety procedures. ERDF conducted a deep safety analysis, and elaborated some adjustments during the installation to comply with safety procedures. The work must implicate every stakeholder: manufacturers, ERDF control and operation teams, fire-fighters, municipality, owner of the site…

For now, only one storage asset is under operation and the charge/discharge schedules are sent from the ACR. Later on, once the Network Battery Aggregator (NBA) is implemented, it will be able to send instructions to the four storage assets, as well as to aggregate them in order to deliver services for the different use cases.

### 3.1.10 Glossary

#### Agency for Maintenance and Operation of Primary Substation (AMEPS)

This agency is in charge of the operation of primary substations, on a 24/24 basis. The technicians maintain and operate the primary substations, and are involved in the operation of the PSB storage asset. Outside workable hours, they are able to set the storage asset on safety mode. During workable hours, they are able to troubleshoot the storage asset.

#### Contactor

A contactor is an electrically controlled switch used for switching a power circuit, similar to a relay except it has higher current ratings. A contactor is controlled by a circuit which has a much lower power level than the switched circuit. Within the NICE GRID storage asset, each ESSU has a contactor.

#### Control and operation of the distribution grid

Within ERDF, grid management is separated between control (remotely) and operation (on site). Control is done by the **ACR**, which monitors only the MV grid and primary substations, and BECS, which is in charge of LV grid and secondary substation. **ACR** is working 24/24. Operation is done by AMEPS for primary substations and AREX for the MV and LV grid. **ACR** can call on technicians from AMEPS and AREX to intervene on site, and the technicians have to report to the **ACR**.

#### DEIE

**DEIE** = ***D****ispositif d'****E****change d'****I****nformation* ***E****xploitation* = Device for exchanging operating information.

The DEIE is a communicating device installed between a renewable energy generator connected to the MV grid and the **Regional Control Center (ACR).**

Its functionalities are:

- Displaying U (voltage), P (active power) and Q (reactive power)
- Coupled/decoupled state

Its order abilities are:

- Decoupling
- Limitation of generation power to a set value (P and Q)
- Modification of the automatic isolation during works under MV voltage
- Load shedding request

Within the NICE GRID project, the DEIE allows the ACR to remotely switch off the power supply circuit of the PSB storage asset.

#### Islanding

In the NICE GRID project, islanding consists in disconnecting a secondary substation feeding 12 commercial clients from the main grid and supplying it only with a Li-ion based storage asset and installed PV generators

#### Linky meter

Linky is a communicating meter, which means that it can receive and send data without the need for the physical presence of a technician. Installed in end-consumer's properties and linked to a

supervision centre, it is in constant interaction with the network. The Linky meter is able to receive orders and transmit information remotely. To do this, it communicates to a hub, a kind of mini-computer installed inside transformation substations managed by ERDF. The hub is linked to the ERDF supervision centre.

### Master Control Unit (MCU)

The Master Control Unit (MCU) is a computer responsible for monitoring the PSB storage asset; it communicates with the Field Control Units (FCU) installed at each storage asset level (SSB and LVGB). Through a small SCADA system, the Master Control Unit can act as data historian, protocol driver, etc., minimising the dependency of the system reliability on the communication availability. The Distributed Control Units support advanced power applications such as active power control, voltage fluctuation smoothing and islanding monitoring.

The communication links are the following:

- For the PSB storage assets: PCS <> MCU <> **ACR** and NBA
- For the SSB and LVGB: PCS <> FCU <> MCU <> **ACR** and NBA
-

### Power Converter System (PCS)

The PCS is a bidirectional system which makes it possible to charge the batteries from the grid and to discharge the batteries on the grid. Relying on an **I**nsulated-**G**ate **B**ipolar **T**ransistor (**IGBT**[20]**) based 4-quadrant converter system**; it can convert direct current into alternate current and vice versa. It serves as charger of the battery, can manage set points for the battery, and is retrieving the battery alarms. PCS communicates with the MCU to exchange storage assets state values, set points, alarms.

### Regional Control Centre (ACR)

The 31 *Agence Conduite Régionale* (ACR)= Regional Control Center, ensure the proper functioning of the MV grid 24 / 24. Each one ensures continuity of supply to one to two million of end customers. ACRs are always looking to optimize the power scheme by allocating the most favorable power flows in primary substations (PS), on the MV network and secondary substations. They aim to restore quickly the customer supply in the event of a service interruption. They also ensure secure access to the network for technician interventions (operating staff, subcontracting companies).

### Storage asset

A storage asset is a combination between a battery working with direct current (DC) and a Power Converter System (PCS) working as a charger for the battery and a bidirectional converter from direct current (DC) to alternative current (AC).

### Storage asset HMI

[20] The insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device primarily used as an electronic switch. In newer devices, it is noted for combining high efficiency and fast switching.

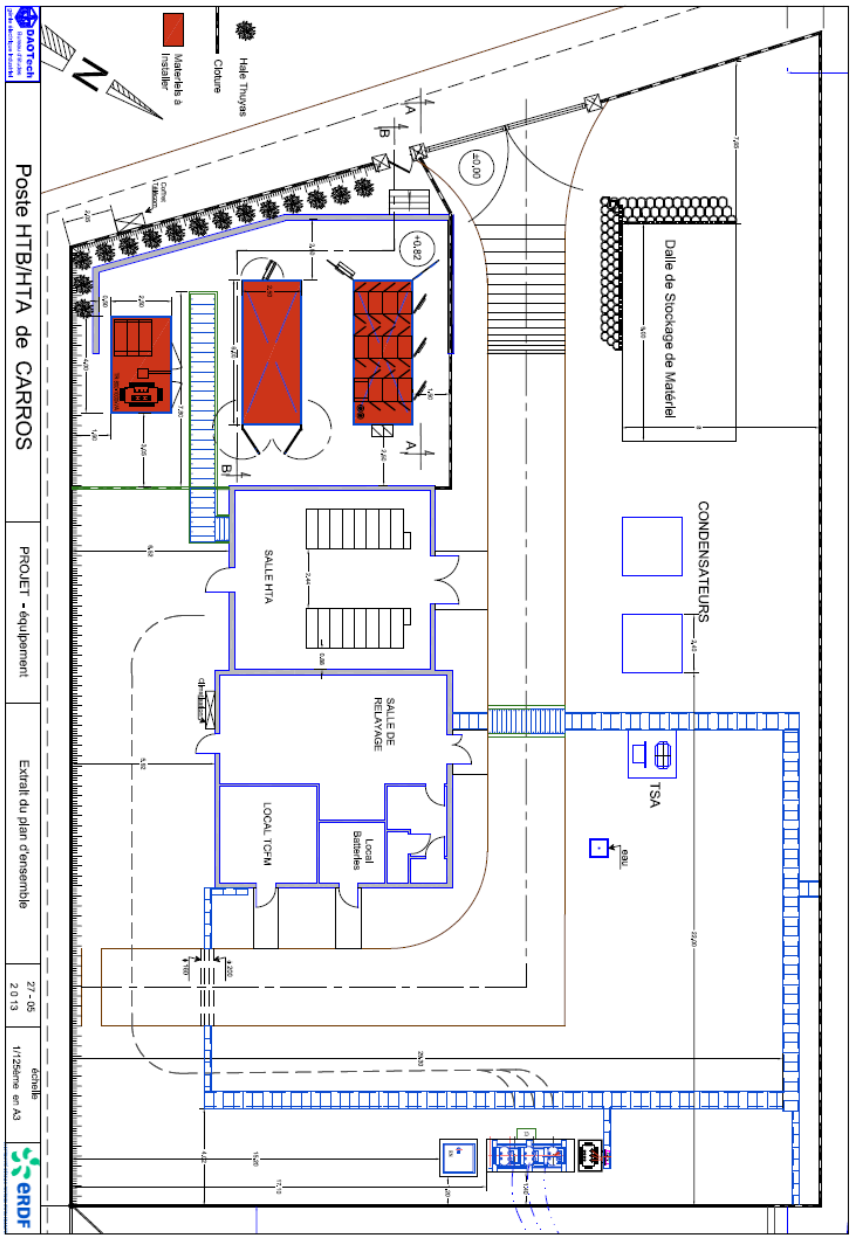
The storage asset HMI is a Human Machine Interface (HMI) located at the **Regional Control Centre (ACR)** designed for the remote display of the storage assets state and the monitoring of these assets.

| Acronyms | Definition |
|---|---|
| **ACR** | ***A**gence **C**onduite **R**égionale* = Regional Control Center |
| **AMEPS** | ***A**gence de **M**aintenance et **E**xploitation des **P**ostes **S**ources* = Agency for maintenance and operation of primary substation |
| **AREX** | ***A**gence d'**E**xploitation **R**éseau* = Agency for grid operation |
| **BMM** | **B**atteries **M**anagement **M**odule (SAFT) |
| **BPL** | **B**roadband over **P**ower **L**ines (Modem ALSTOM) |
| **CAN** | **C**ontrolled **A**rea **N**etwork |
| **DEIE** | *Dispositif d'Echange d'Information d'Exploitation* = device used to opean remotely the main circuit breaker of the storage asset |
| **DREAL** | ***D**irection **R**égionale de l'**E**nvironnement, de l'**A**ménagement et du **L**ogement* = Regional Directorate for Environment, Planning and Housing |
| **DSO** | **D**istribution **S**ystem **O**perator |
| **ESSU** | **E**nergy **S**torage **S**ystem **U**nit (SAFT Batteries) |
| **FCU** | **F**ield **C**ontrol **U**nit (ALSTOM) |
| **FSS** | **F**ire **S**afety **S**ystem |
| **GDP** | **G**eneral **D**istribution **P**anel |
| **HMI** | **H**uman **M**achine **I**nterface |
| **HVAC** | **H**eating **V**entilation **A**ir **C**onditioning |
| **ICPE** | **C**lassified **I**nstallations for the **P**rotection of **E**nvironment |
| **LV** | **L**ow **V**oltage |
| **LVGB** | **L**ow **V**oltage **G**rid **B**attery |
| **MBMM** | **M**aster **B**atteries **M**anagement **M**odule (SAFT Batteries) |
| **MCU** | **M**aster **C**ontrol **U**nit (ALSTOM) |
| **MV** | **M**edium **V**oltage |
| **NBA** | **N**etwork **B**atteries **A**ggregator (which controls the operation of grid batteries) |
| **NEM** | **N**etwork **E**nergy **M**anager |

| | |
|---|---|
| **PCB** | **P**arallel **C**ircuit **B**reaker |
| **PCS** | **P**ower **C**onverter **S**ystem |
| **PSB** | **P**rimary **S**ubstation **B**attery |
| **PV** | **P**hoto**V**oltaic |
| **SOC** | **S**tate **O**f **C**harge of the batteries |
| **SOH** | **S**tate **O**f **H**ealth of the batteries |
| **SSB** | **S**econdary **S**ubstation **B**attery |
| **TSO** | **T**ransmission **S**ystem **O**perator |
| **UPS** | **U**ninterruptible **P**ower **S**upply |

### 3.1.11 Appendices

- **Appendix 1 – Primary substation map**



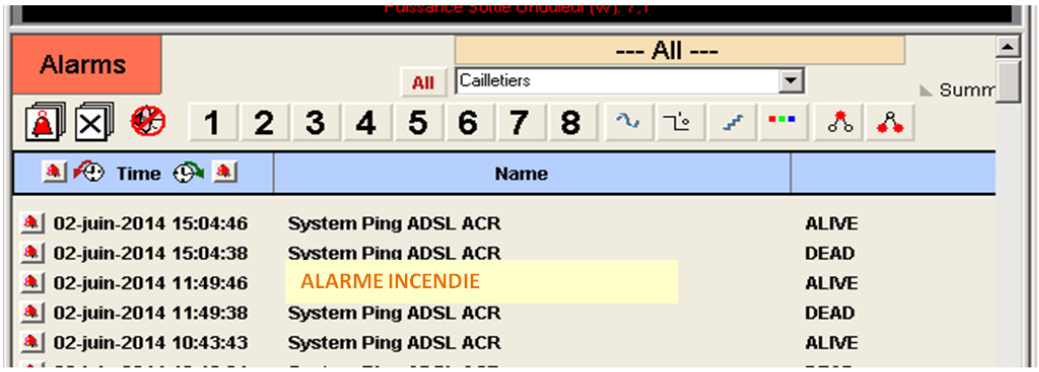
- **Appendix 2 – Technical date of the PSB storage asset**

| **Main electrical characteristics** | | |
|---|---|---|
| Nominal voltage | 730 | V |
| Maximum voltage | 818 | V |
| Minimum voltage | 609 | V |
| Nominal capacity (C/3, 20°C) | 820 | Ah |
| Minimum capacity (C/3, 20°C) | 800 | Ah |
| Maximum continuous charge current | | |
| @ +25°C | 505 | A |
| @ 0°C | 180 | A |
| @ - 20°C | 80 | A |
| Maximum continuous discharge current | 1600 | A |
| **Mechanical characteristics** | | |
| Container height (ISO 668) | 2896 max | mm |
| Container width (ISO 668) | 2438 max | mm |
| Container length (ISO 668) | 6058 max | mm |
| Weight | 15 000 | kg |
| Ingress Protection operational | IP34 | |
| Ingress Protection transport | IP54 | |
| **General characteristics** | | |
| Operating battery temperature range | -20 to +55 | °C |
| Storage battery temperature range | -20 to +55 | °C |
| Maximum Relative Humidity | 100 | % |
| Normal operating altitude (maximum) | 2000 | m |
| Storage and transport altitude (maximum) | 3000 | m |
| EMC | CEI 62040-2<br>Category C3 | |
| Insulation | EN 50178<br>Overvoltage Category II<br>Insulation resistor @ 1000VDC: > 100 MOhm<br>Dielectric: 3000 Vrms<br>Leakage current > 3,5 mA | |
| Dust | CEI 60721-3-1 & -4 Class S4 | |
| Chemical pollution | CEI 60721-3-1 & -4 Class C3 | |
| Biologic pollution | CEI 60721-3-1 Class B3 | |
| Wind | CEI 60721-3-4 Class 4Z5 50m/s (except roof) | |
| Heat | CEI 60721-3-4 Class 4Z1 | |

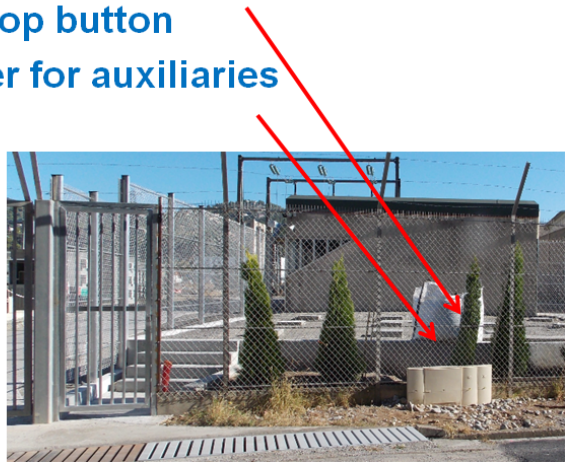
- **Appendix 3 – Safety procedure for the PSB**

## IF THE FIRE ALARMS SOUNDS

- *The triggering of the alarm appears under this form on the « black » Human Machine Interface (HMI):*

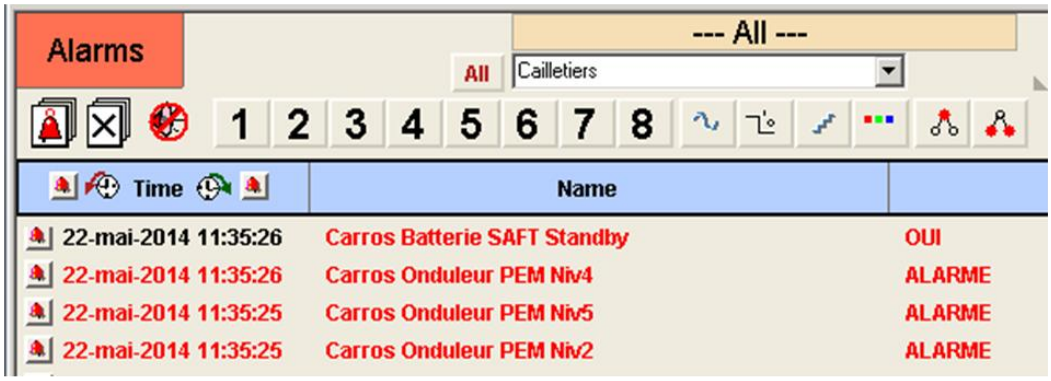

Alarms
--- All ---
All
Cailletiers
1 2 3 4 5 6 7 8
Time
Name
02-juin-2014 15:04:46 System Ping ADSL ACR ALIVE
02-juin-2014 15:04:38 System Ping ADSL ACR DEAD
02-juin-2014 11:49:46 ALARME INCENDIE ALIVE
02-juin-2014 11:49:38 System Ping ADSL ACR DEAD
02-juin-2014 10:43:43 System Ping ADSL ACR ALIVE

1. **Open the feeder "SAFT" in the primary substation**
2. **Call firemen SDIS 06 au 04 93 22 75 90 for intervention at the battery of the primary substation "BROC CARROS", remind that the battery must not be sprayed with water (only carbon dioxide $CO_2$)**
3. **Call the ERDF agency "AMEPS"**
   a. **Push the emergency stop button**
   b. **Open the circuit breaker for auxiliaries**



# WHAT TO DO IN CASE OF ALARM

*An alarm appears under this form on the « black » Human Machine Interface (HMI)*


Alarms
--- All ---
All
Cailletiers
1 2 3 4 5 6 7 8
Time
Name
22-mai-2014 11:35:26 Carros Batterie SAFT Standby OUI
22-mai-2014 11:35:26 Carros Onduleur PEM Niv4 ALARME
22-mai-2014 11:35:25 Carros Onduleur PEM Niv5 ALARME
22-mai-2014 11:35:25 Carros Onduleur PEM Niv2 ALARME

**Alarm level 1 or 2**:

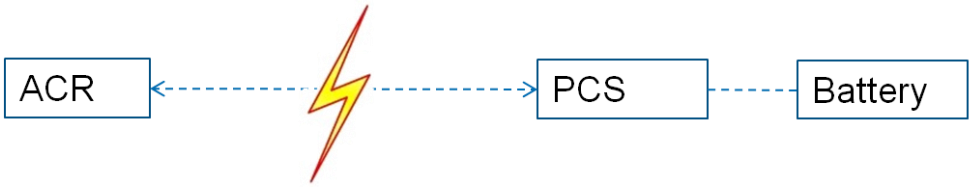
**no action from the ERDF *"Agence Conduite Régionale"***

**Alarm level 3, 4 or 5:**

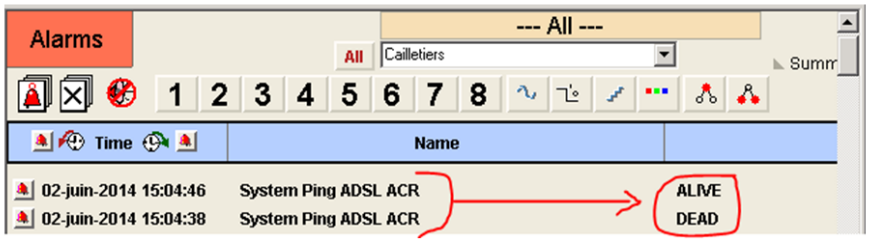
1. **Check that the battery status changed from "Stop" to "Standby"**
2. **Check that the number of closed contactors = 0**

3. **If number of closed contactors >0, open the "non urgent DEIE SAFT-GRID from the feeder "SAFT"**

## ALARM « INTERUPTION OF ACR-PCS CONNECTION > 1 MIN»




- *This appears under this form on the « black » Human Machine Interface:*




☞ **Open the *"non urgent DEIE SAFT-GRID"* from the feeder "SAFT"**

## 3.2 Halfway assessment of grid batteries and converters experiments

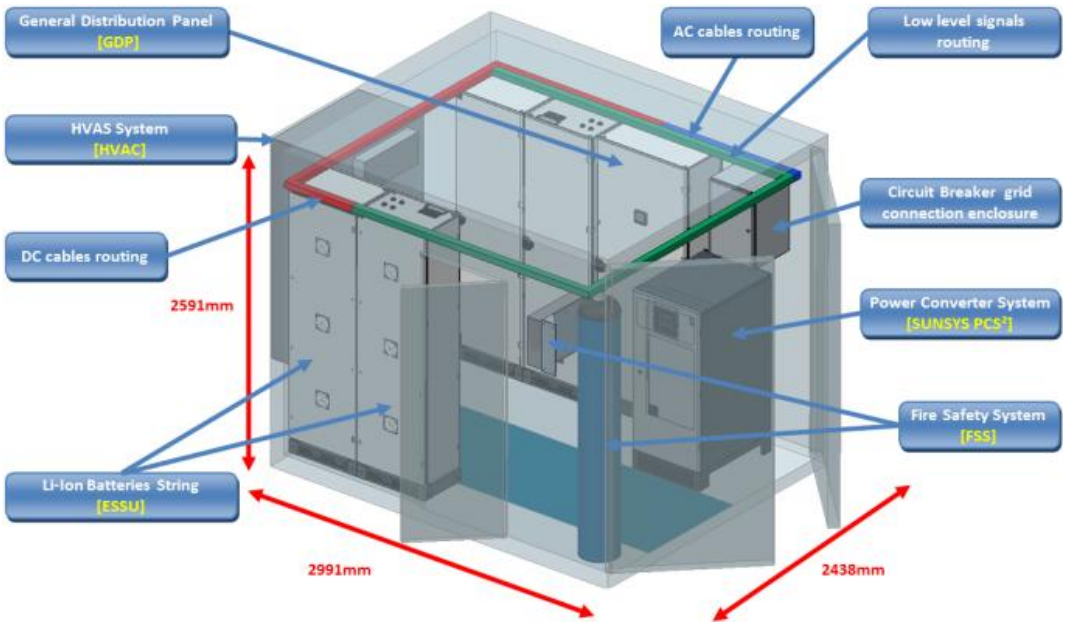
The target of this section is to describe all the tests which have been performed on the SUNSYS PCS² 33TR in order to **demonstrate the compliance of its functionalities, capabilities, performances & protections** with the requirements of the Nice Grid project for the On Grid application.

In this project, the SUNSYS PCS² 33TR is associated with the following equipment:

- Lithium-Ion batteries + their management system ➔ SAFT.
- BPL Modem + Field Control Unit (FCU) ➔ ALSTOM.

So, a part of the tests plan was dedicated to the compatibility between these equipment and theirs interfaces.

In the real application of the Nice Grid project, all these equipment will be integrated in 3 10ft containers of 33kW and 106kWh like illustrated by the following figure:




For the preliminary tests described hereafter, the devices were not integrated in the container and were not associated with the additional auxiliaries like the HVAC (Air conditioning) and the FSS (Fire Safety System).

The full tests of the container will be performed in September & October 2014 after its construction in the SOCOMEC factory and in Concept Grid (EDF R&D laboratory). These tests are not critical, in case of gap with the expectations, because the impact will affect only the logical sequences (easy to solve).

| Acronyms | Definition |
|---|---|
| **AGDP** | **A**utomatic **G**rid **D**isconnection **P**rotection. |
| **AID or AIP** | **A**nti-**I**slanding **D**evice or **P**rotection |
| **BMM** | **B**atteries **M**anagement **M**odule (SAFT) |
| **BPL** | **B**roadband over **P**ower **L**ines (Modem ALSTOM) |
| **CAN** | **C**ontrolled **A**rea **N**etwork |
| **CB** | **C**ircuit **B**reaker |
| **DSO** | **D**istribution **S**ystem **O**perator |
| **ECSE** | **E**nergy **C**onverter & **S**torage **E**quipment (SOCOMEC Converter + SAFT Batteries) |
| **EMS** | **E**nergy **M**anager **S**ystem (~NEM & NBA in the Nice Grid Project) |
| **ESSU** | **E**nergy **S**torage **S**ystem **U**nit (SAFT String Batteries) |
| **FCU** | **F**ield **C**ontrol **U**nit (ALSTOM) |
| **FSS** | **F**ire **S**afety **S**ystem. |
| **GDP** | **G**eneral **D**istribution **P**anel. |
| **HMI** | **H**uman **M**achine **I**nterface. |
| **HVAC** | **H**eating **V**entilation **A**ir **C**onditioning**.** |
| **IMD** | **M**aximum **D**ischarge **C**urrent. |
| **IMR** | **M**aximum **C**harge **C**urrent (max 5 seconds). |
| **IMR_C** | **M**aximum **C**ontinuous **C**harge **C**urrent. |
| **LBS** | **L**oad **B**reak **S**witch**.** |
| **MBMM** | **M**aster **B**atteries **M**anagement **M**odule (SAFT) |
| **MCU** | **M**aster **C**ontrol **U**nit (ALSTOM) |
| **NBA** | **N**etwork **B**atteries **A**ggregator (which controls the operation of grid batteries) |
| **NEM** | **N**etwork **E**nergy **M**anager |
| **PCS²** | **P**ower **C**onverter & **S**torage **S**ystem (SOCOMEC) |
| **PDO** | **P**rocess **D**ata **O**bject (CANOpen) |
| **PLC** | **P**ower **L**ine **C**ommunication **C**arrier |

| | |
|---|---|
| **PV** | **P**hoto**V**oltaic |
| **RPDO** | **R**eceived **P**rocess **D**ata **O**bject (CANOpen) |
| **RSDO** | **R**eceived **S**ervice **D**ata **O**bject (CANOpen) |
| **SC** | **S**hort-**C**ircuit |
| **SDO** | **S**ervice **D**ata **O**bject (CANOpen) |
| **SMU** | **S**afety and **M**onitoring **U**nit (electronic board inside each battery module) |
| **SOC** | **S**tate **O**f **C**harge of the batteries. |
| **SOH** | **S**tate **O**f **H**ealth of the batteries. |
| **SPD** | **S**urge **P**rotection **D**evice. |
| **TPDO** | **T**ransmitted **P**rocess **D**ata **O**bject (CANOpen) |
| **TSDO** | **T**ransmitted **S**ervice **D**ata **O**bject (CANOpen) |
| **TSO** | **T**ransmission **S**ystem **O**perator. |
| **UPS** | **U**ninterruptible **P**ower **S**upply. |
| **VFRT** | **V**oltage **F**ault **R**ide **T**hrough |
| **VMD** | **M**aximum **C**harge **V**oltage |
| **VMR** | **M**inimum **D**ischarge **V**oltage |

### 3.2.1 Technical reminders

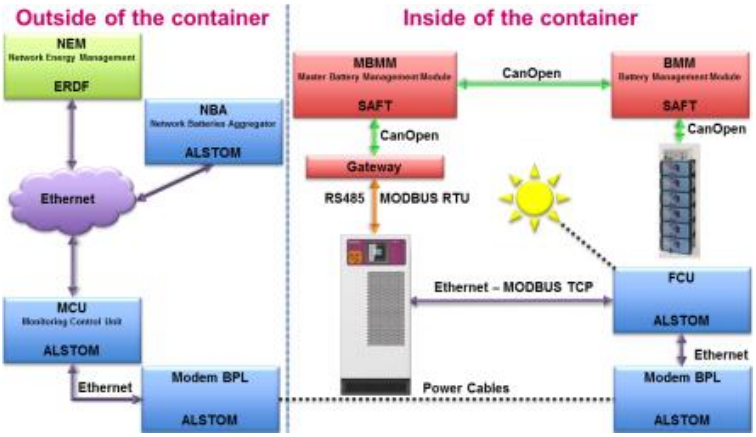
- **Objective of the full system**

The 33kW containers will be localized on 2 different points of the LV grid in order to support it in the stability of electrical values (mainly the voltage in our study case).

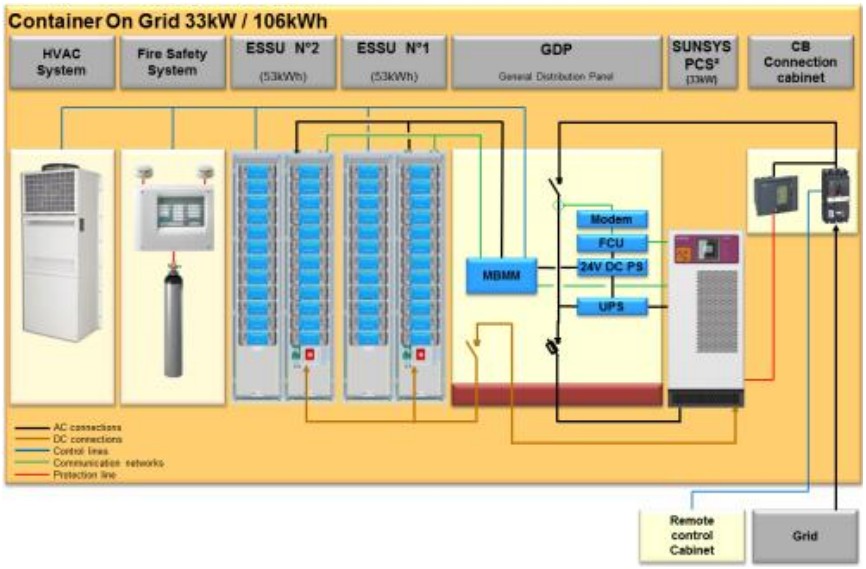
This type of system will ensure the management (shaving / shifting / …) of the local productions & consumptions peaks by receiving, from central system, set points for active power & reactive power (To be confirmed).

The target of the project is to make the demonstration that this kind of solution allows the massive integration of PV plants without impact on the grid and to reduce the reverse currents flows on it.

- **General communication architecture**



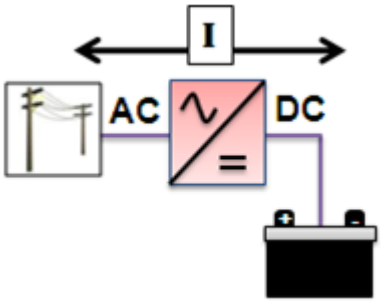

- **Simplified single line Diagram**



### 3.2.2 Equipment description

- **SUNSYS PCS² 33TR (TR = with insulation transfomer)**
  - ***Introduction***

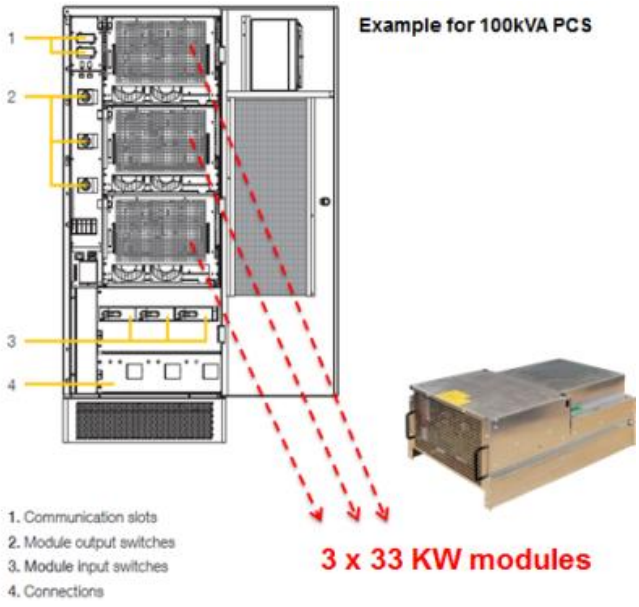
The SUNSYS PCS² Family is a **bidirectional** converter system acting as a **current generator**:



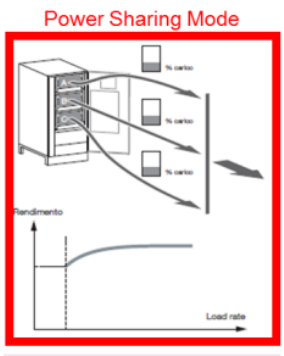

The SUNSYS PCS² is a modular architecture solution (Modulo 33kW) which allows:

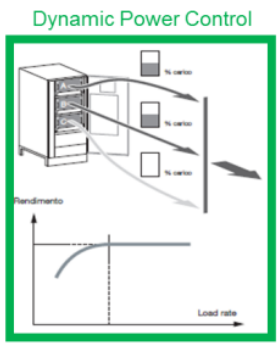
- A maximised yield thank to Dynamic Power Control function (DPC).
- An upgradeable solution.
- A high level of availability.
- Easy, secured & fast maintenances operations thanks to Hot-Swap solution.

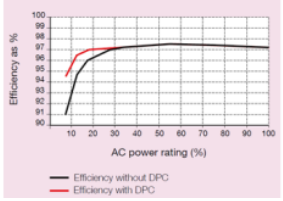
- ***Modular Architecture:***




- ***DPC Function:***
  - Power Sharing Mode :
    - All the converter modules work permanently in parallel and balance each other the requested power whatever the level of this power.
  - Dynamic Power Control :
    - This function allows a "wattmetric" management of the modules. According to the power requested by the battery or the load, the PCS² will use only the optimized number of converter modules.



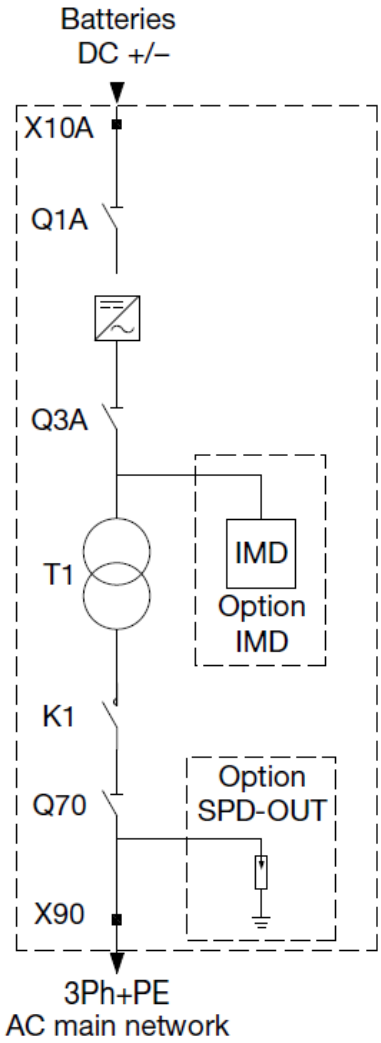




**BENEFITS**
- Higher efficiency at low power.
- Longer life of the converter.
- Lower dissipation.
- Reduced need for air conditioning.
- Less noise.

The PCS SUNSYS is already ready to be interfaced with its environment:

- Network Management System / Scada (NEM).
- Batteries Management System (BMS).
- Compatible with different type of batteries technologies.

- ***Internal single line diagram***




- ***Technical features***
  - Electrical features :

| | | |
|---|---|---|
| **DC input** | Voltage [VDC] | 450 ➔ 850 |
| | Max Current (Charge & Discharge) [A] | 80 |
| **AC output** | Nominal voltage [VAC] | 400 (3PH) |
| **(Integrated** | Voltage range [VAC] | 320 ➔ 480 (3PH) |

| | | | |
|---|---|---|---|
| **output transformer)** | Frequency | [Hz] | 50 |
| | Frequency range | [Hz] | 47,5 ➔ 51,5 |
| | Rated power | [W] | 33 300 |
| | Maximum power | [%] | 110% for 30 min |
| | Rated current | [A] | 48 |
| | Max current | [A] | 53 |
| | Power factor range | | +/-1 |
| | Total harmonic distortion | [%] | < 3 |
| | Efficiency (according to European standard) | [%] | 96 |
| | Consumption | [W] | 30 (Control Unit) |

- Mechanical features :

| | | | |
|---|---|---|---|
| **Dimensions** | Height | [mm] | 1400 |
| | Width | [mm] | 600 |
| | Depth | [mm] | 795 |
| | Surface | [m²] | 0,5 |
| **Weight** | | [kg] | 330 |
| **Noise** | | [dB] | < 60 |

- Environmental conditions :

| | | | |
|---|---|---|---|
| **Thermal** | Operating temperature range | [°C] | -5 ➔ +40 |
| | Environmental category | | Indoor space |
| | Dissipation | [W] | 1 750 |
| | Requested cooling | [$m^3$/h] | 1280 |

| | | | |
|---|---|---|---|
| **Humidity** | Without condensation | [%] | 5 ➔ 95 |
| **Altitude** | Without de-rating | [m] | 1 000 |

- Compliance with standards and directives

| CERTIFICATION | REFERENCE STANDARDS |
|---|---|
| CE MARK | 2004/108/CE EMC<br>2006/95/CE Safety Low Voltage |
| Marked for inverter safety (TUV) | EN 62109-1 EN 62109-2<br>EN 60950-1-2007 (Information transmission system only) |
| EMC test | EN 61000-6-3 : 2007<br>EN 61000-6-2 : 2006<br>EN 61000-3-12 : 2006<br>EN 61000-3-11 : 2001 |

As the SUNSYS PCS² range is globally based on the SUNSYS PV inverter range most of the standards & directives compliancy have been already qualified by a third party.

## SAFT Lithium-Ion Batteries & their management system

### *Introduction*

Within the frame of NICE GRID project SAFT will deliver a battery system solution based on Li-ion technology. This technology is used for enhanced capabilities for both energy and power discharges.

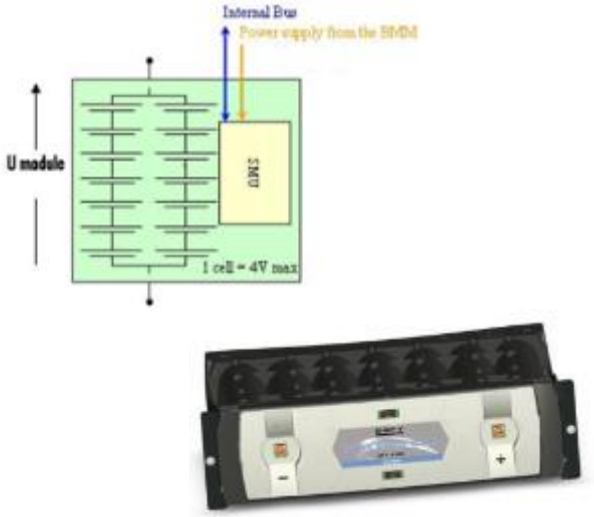
Using modular construction, SAFT has designed a standard and scalable energy storage solution that meets a wide variety of application needs.

The system relies on three main modules:

- The SYNERION = Module of lithium-ion module
- The BMM = Batteries Management Modules for 1 string of SYNERION modules.
- The MBMM = Master Batteries Management Modules for several BMM management.

### *SYNERION LI-ION MODULES*

In order to reach ESSU voltage levels, the battery is based on a modular architecture with a 28VDC maximum voltage module. The module consists of 14 cells willing in two branches in parallel of seven cells each. This assembly is named 2P7S.




*SYNERION 2P/7S module characteristics*
*SYNERION 24E 2P/7S model view*

The Synerion Battery module is realised with following sub-parts:

- one "SMU_I" electronic board.
- one "BUSBAR" electronic board.
- harness between electronics boards.

The main functions ensured by the SMU_I board are to:

- monitore each cells voltage,
- monitore module temperature at different points,
- balance each cells,
- calculate module SOH,

- send cells voltage, module temperatures, alarms information, SOH,
- receive self-test request, alarms reset request, balancing consign, current SOC,
- manage self-test to verify the functionalities,
- manage power-supply,
- converte module voltage (to 5V) to supply High-Voltage electronic functions,
- wake-up and deactivation when an external supply signal is present or not,
- control self-power signal to be supplied even if the external signal is not present,
- communicate with maintenance tool (diagnostic and reprogramming),
- protecte and filter inputs and outputs.

Each module contains:

- two power interfaces (one for the positive and the other one for negative),
- two signal connectors (same connector / one for the input and the second one for the output signal).

- ***BMM:***

The ESSU is a high power energy storage system compatible with high DC voltage and performance which could reach up to 1KV & 160kW / ESSU.

Each ESSU (Energy Storage System Unit) is an electrical string of 24 series connected modules and a BMM, altogether assembled into a double-side 19" rack.

The Battery Management Module (BMM) will perform all the functions necessary to manage and protect the Li-ion cells.

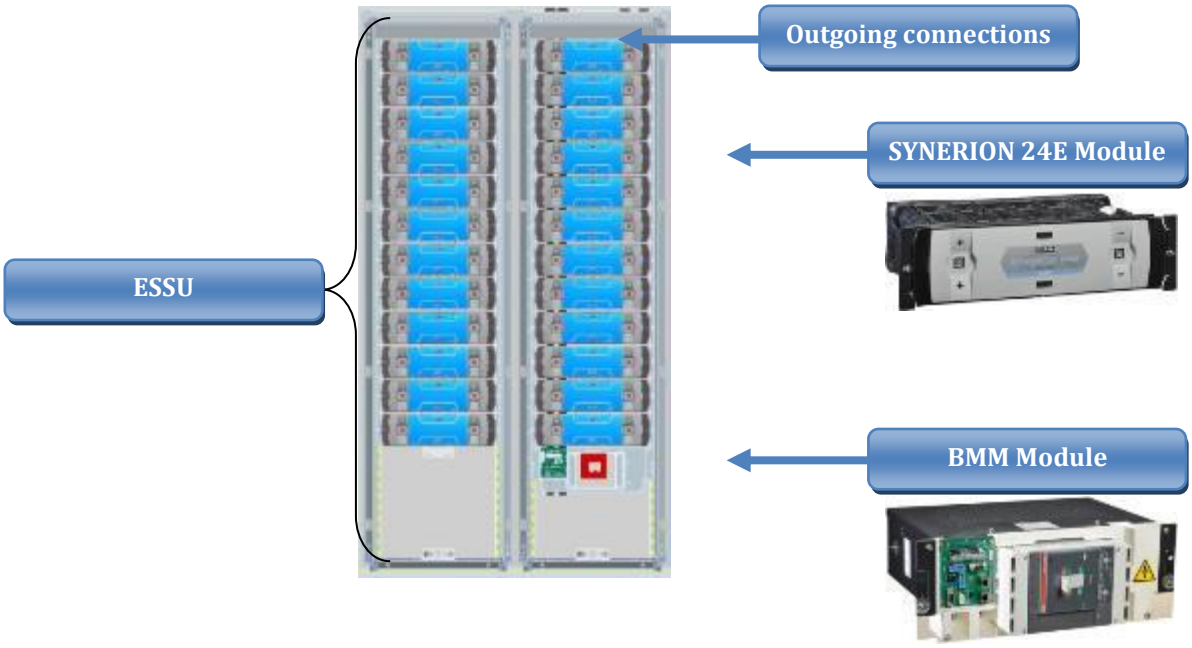
An electronic module (called BMM) is required to manage and monitor several Synerion modules serial connected.

The main functions of the BMM are :

- Monitoring each module of the string (voltage, temperature, current, alarms),
- Protecting the string with battery algorithms (IMD, IMR, etc),
- Managing the electrical connection of the string on the DC Bus (opening / closing contactor),
- Communicating with the MBMM.

The modules and the BMM are mounted in 19” cabinets.

- ***ESSU integration***


Outgoing connections
SYNERION 24E Module
ESSU
BMM Module

- ***Technical Features***
  - **Electrical features:**

    - SYNERION Module 24E (at 25°C):

| | | |
|---|---|---|
| **Voltage** | Nominal [VDC] | 25,2 |
| | Max [VDC] | 28,2 |
| | Min [VDC] | 21 |
| **Current** | Maximum continuous discharge [A] | 160 |
| | Maximum continuous recharge [A] | 45 |
| **Power** | Maximum continuous discharge [W] | 3800 |
| | Maximum continuous recharge [W] | 1150 |
| | Peak discharge (in 5 sec) [W] | 8500 |
| | Peak recharge (in 5 sec) [W] | 5500 |
| **Capacity** | (C/5 @ 25°C) [Ah] | 87 |
| **Energy** | (C/5) [Wh] | 2200 |
| **Duration** | Recharge time [h] | 3 |

    - BMM Module:

| | | |
|---|---|---|
| **Voltage** | Nominal (up to) [VDC] | 1000 |
| **Current** | Maximum continuous [A] | 200 |
| **Power Consumption** | Inrush 300ms [W] | 90 |
| | Stabilized [W] | 7 |
| **Power supply** | [VDC] | 24 +/-5 |

- ESSU panel (24 Modules SYNERION 24E + 1 BMM at 25°C):

| | | |
|---|---|---|
| **Voltage** | Nominal [VDC] | 605 |
| | Max [VDC] | 677 |
| | Min [VDC] | 504 |
| **Current** | Maximum continuous discharge [A] | 160 |
| | Maximum continuous recharge [A] | 45 |
| **Power** | Maximum continuous discharge [W] | 91 200 (***TBC by SAFT***) |
| | Maximum continuous recharge [W] | 27 600 (***TBC by SAFT***) |
| | Peak discharge (in 5 sec) [W] | 204 000 (***TBC by SAFT***) |
| | Peak recharge(in 5 sec) [W] | 132 000 (***TBC by SAFT***) |
| **Capacity** | [Ah] | 87 |
| **Energy** | [Wh] | 52 800 |

- ***Mechanical features:***

  - SYNERION Module24E:

| | | |
|---|---|---|
| **Dimensions** | Height [mm] | 131 |
| | Width [mm] | 448 |
| | Depth [mm] | 293 |
| **Weight** | [kg] | 18,5 |

  - BMM Module:

| | | |
|---|---|---|
| **Dimensions** | Height [mm] | 177 |
| | Width [mm] | 483 |
| | Depth [mm] | 385 |
| **Weight** | [kg] | 14,2 |

  - ESSU panel (24 Modules SYNERION 24E + 1 BMM):

| | | |
|---|---|---|
| **Dimensions** | Height [mm] | 2 000 |
| | Width [mm] | 1 200 |
| | Depth [mm] | 400 |
| **Weight** | [kg] | ~600 |

- **Environmental conditions:**

- SYNERION Module 24E:

| | | |
|---|---|---|
| **Thermal** | Operating temperature range [°C] | +10 ➔ +40<br>**Optimum at +30°C** |
| | Dissipation [W] | ~10 |
| | Requested cooling [$M^3$/h] | Natural convection |
| **Humidity** | Without condensation [%] | < 60<br>**Optimum at 50%** |
| **Altitude** | [M] | 2 000 |

- BMM Module:

| | | |
|---|---|---|
| **Thermal** | Operating temperature range [°C] | -20 ➔ +60 |
| | Dissipation [W] | **?** |
| | Requested cooling [$M^3$/h] | Natural convection |
| **Humidity** | Without condensation [%] | 95 |
| **Altitude** | [M] | 3 000 |

- ESSU panel (24 Modules SYNERION 24E + 1 BMM):

| | | |
|---|---|---|
| **Thermal** | Operating temperature range [°C] | +10 ➔ +40<br>**Optimum at +30°C** |
| | Dissipation [W] | <300W |
| | Requested cooling [$M^3$/h] | Natural convection |
| **Humidity** | Without condensation [%] | < 60<br>**Optimum at 50%** |

| | | |
|---|---|---|
| **Altitude** | [M] | 2 000 |

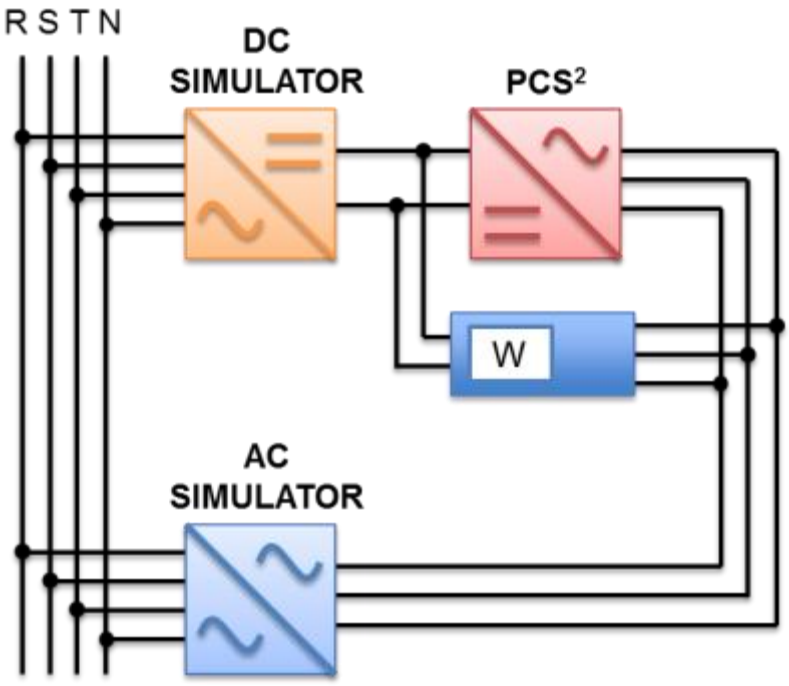
### 3.2.3 Tests description & results

- **SUNSYS PCS² 33TR**
  - ***Tools***

In order to perform the tests described in the following paragraphs, SOCOMEC has built equipment composed of the following main components:

- A grid connection.
- A DC source simulator.
- An AC source simulator.
- A SUNSYS PCS² 33TR.
- Wattmeter (Yokogawa - WT3000).
- An oscilloscope.

*(Details about these components: Brands, models, last calibration or reference are described in the tests reports).*



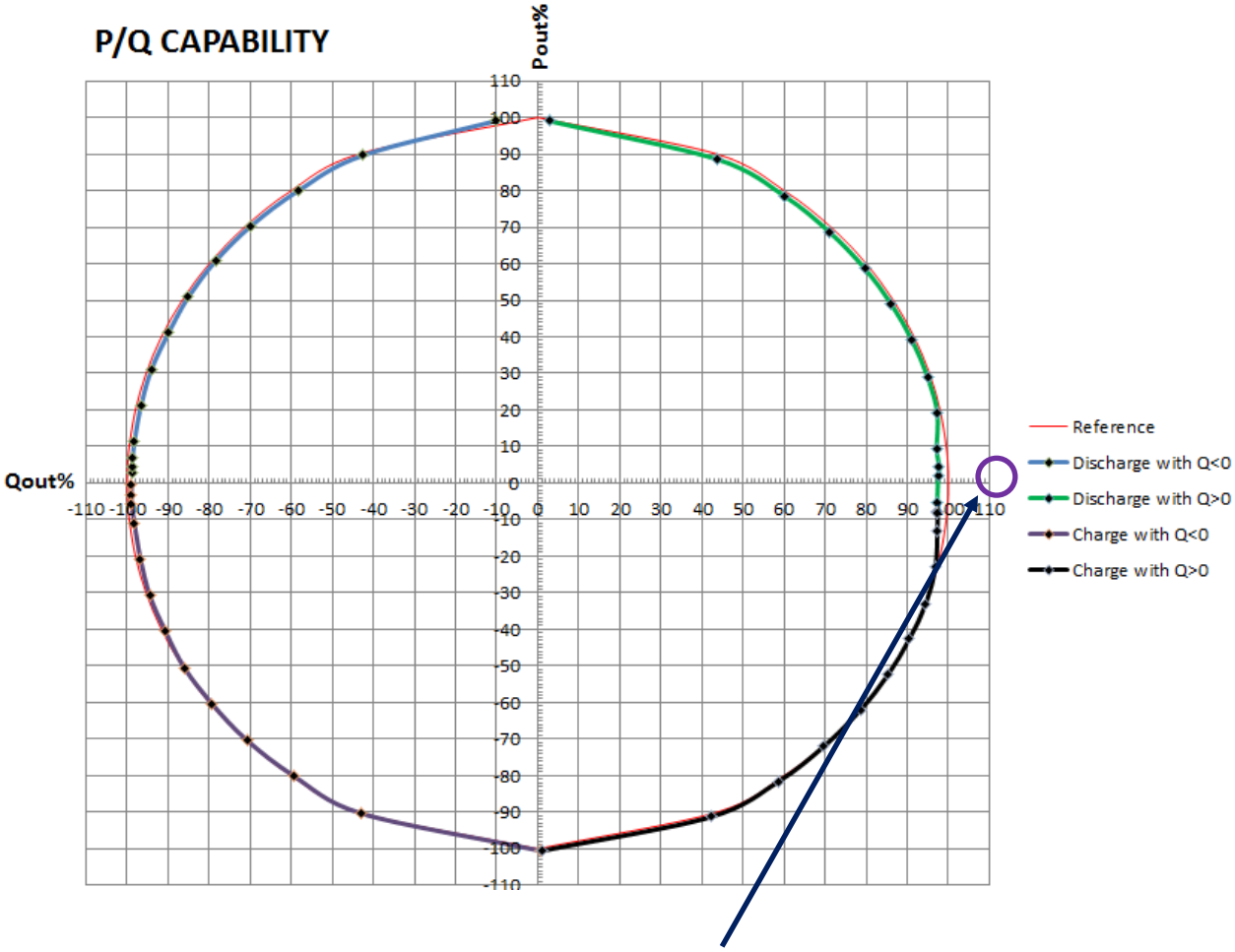
- **Capabilities**
  - ***P/Q circular characteristics***

    Date of the tests: November 2013 & January 2014.

    The objective of this test is to verify that the SUNSYS PCS² is able to **follow the rated power in the four quadrants**:

    - P>0 (Discharging) & Q>0 (Capacitive load).
    - P<0 (Charging) & Q>0 (Capacitive load).
    - P>0 (Discharging) & Q<0 (Inductive load).
    - P<0 (Charging) & Q>0 (Capacitive load).

The target, to pass the tests, is an error < 5%.




**Conclusion**: **The test has been succeeded. (Maximum gap)**

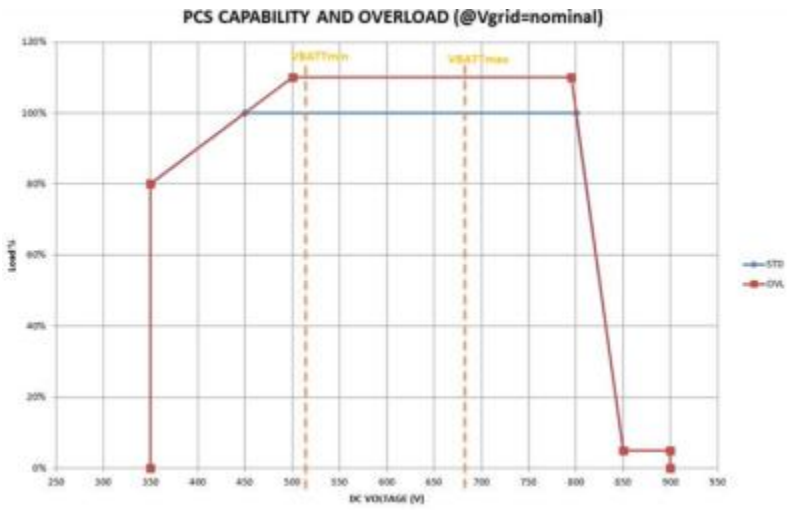
*All the details are described in the internal confidential document*: "Circular_Capability.xlsx"

- ***Overload characteristics***

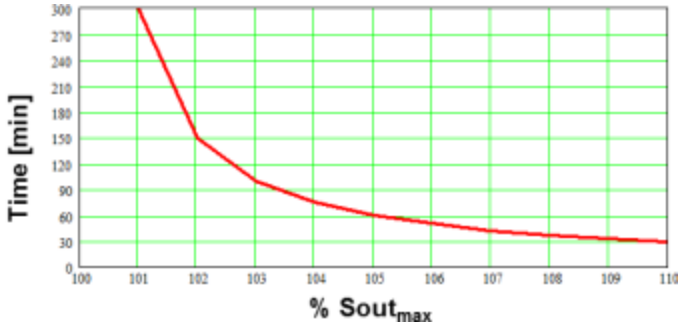
  Date of the tests: November 2013 & January 2014.

The objective of this test is to prove that the SUNSYS PSC² 33TR is able to withstand an **overload situation about 110% during 30 minutes either charging or discharging** sequence with the respect of the Battery voltage range :

| Type | Quantity of modules | V min Module | V max Module | V min String | V max String |
|---|---|---|---|---|---|
| SYNERION 24E | 24 | 21 VDC | 28,2 VDC | 504 VDC | 677 VDC |



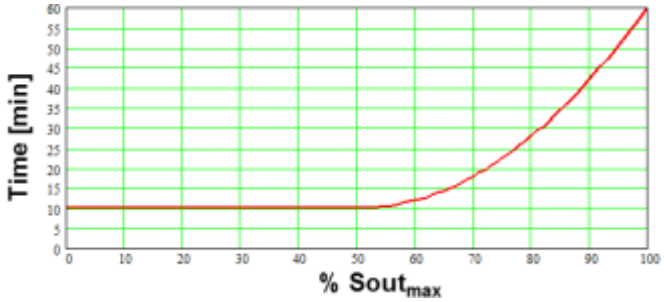

- **The overload capability is regulated from the following function:**




The converter is able to deliver the following maximum power:

- 110% of nominal power for 30 minutes.
- 105% of nominal power for 1 hour.

- **A new overload is possible after a time that it is regulated from the following function:**




The time needed to allow another overload situation is:

- 60 minutes at 100% of nominal power.
- 10 minutes at less than 50% of nominal power.

**Conclusion**: **The test has been succeeded.**

- ***Response time during P & Q set points variations***

  Date of the tests: Date of the tests: November 2013 & January 2014.

The objective of this test is to prove the capacity of the SUNSYS PCS² 33TR to act quickly when a set point is modified.

The target is a **response time lower than 100ms** for the following sequences:

- **Q - Reactive power set points :**

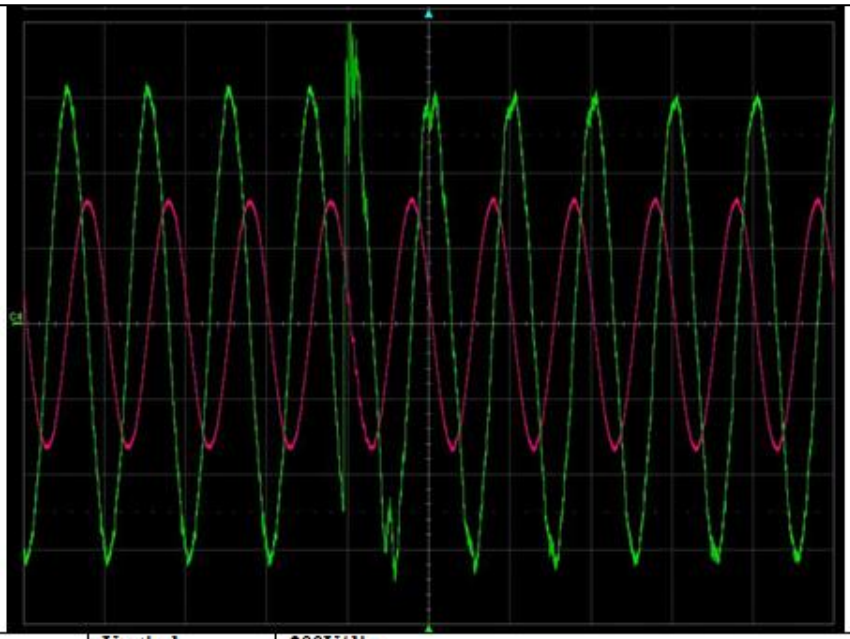
  0% ➔ -50% of Qn (Inductive load)
  0% ➔ -100% of Qn (Inductive load)
  0% ➔ +50% of Qn (Capacitive load)
  0% ➔ +100% of Qn (Capacitive load)
  +100% of Qn ➔ -100% of Qn
  -100% of Qn ➔ +100% of Qn

- **P - Active power set points :**

  0% ➔ +50% of Pn (Discharging)
  0% ➔ +75% of Pn (Discharging)
  +75% ➔ 0% of Pn (Discharging)
  0% ➔ -50% of Pn (Charging)
  0% ➔ -75% of Pn (Charging)
  -75% ➔ 0% of Pn (Charging)

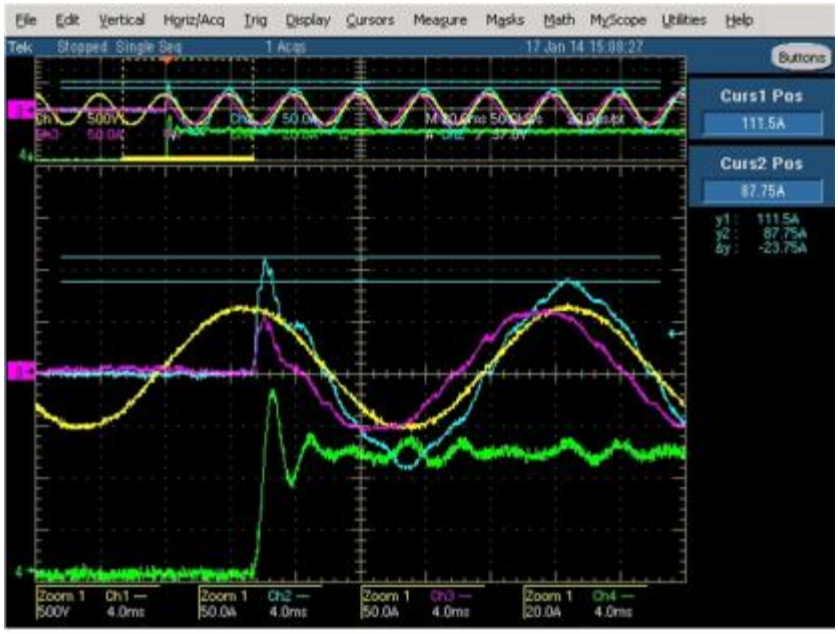
In order to avoid a heavy document, only 1 test of each part will be illustrated hereafter:

- **Q - Reactive power set points (Case N° 5):**



| | | |
|---|---|---|
| CH2(Pink) | Vertical | 200V/div |
| | Timebase | 20ms/div |
| | Description | AC output Voltage |
| CH4(Green) | Vertical | 20A/div |
| | Timebase | 20ms/div |
| | Description | AC output Current |

- **P - Active power set points (Case N°2):**
  - First test – with the original firmware :

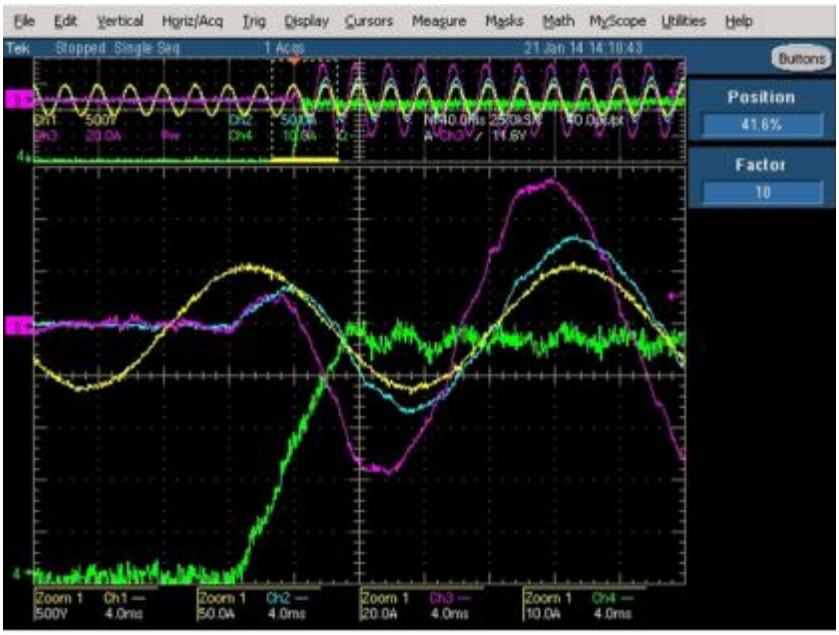



CH1: AC Voltage RS 500V/div CH2: AC Inverter Current phase S 50A/div
CH3: AC Mains Current phase S 50A/div CH4: DC Battery Current 20A/div

A current overshoot can be seen either on the AC side and the DC side. The worst case is when the load is applied in the crest of voltage. The time from 0 to the current overshoot peak is about 1,4ms.

To reduce this effect it has been inserted a ramp to limit this peak.

- Second test with the updated firmware :




CH1: AC Voltage RS 500V/div CH2: AC Inverter Current phase S 50A/div
CH3: AC Mains Current phase S 20A/div CH4: DC Battery Current 10A/div

**Conclusion**: **The test has been succeeded.**

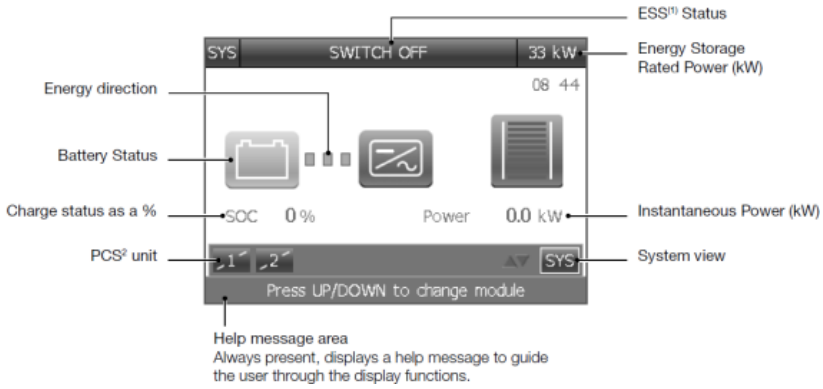
*All the details are described in the internal confidential documents*: "M208_Q_step_response.doc" & "M208_P_step_response.doc"

- **SUNSYS PCS² HMI test**

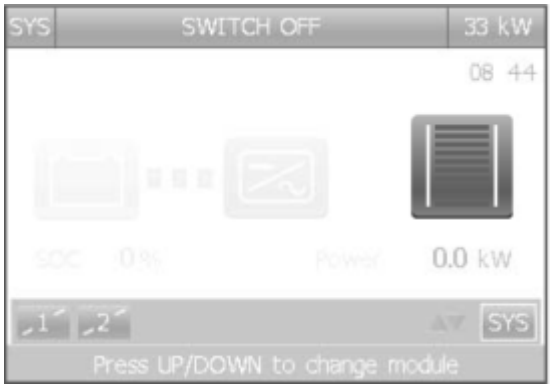
  Date of the tests: February 2014.

  The objective of this test is to verify the conformity of the navigation, the architecture of menus and displays, the animation of the variable status and measures, the parameters, the data logging and the maintenance information.

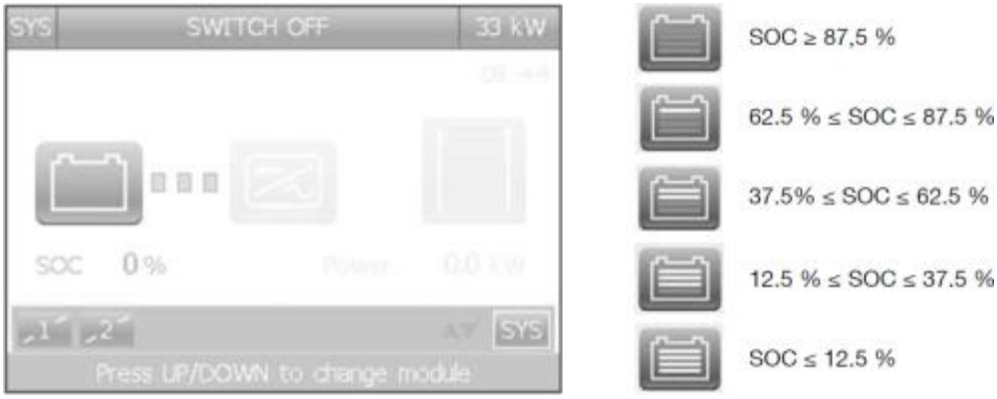
- **The main dashboard screen:**




- **The SUNSYS PCS² power screen:**



- **The Battery status screen:**




- **Tests synthesis:**

| Test | Result | Note |
|---|---|---|
| Display Overview | Redo | In the user manual the figure 8.1.1 is different from synoptic |
| Verify the two graphics conditions: charges and discharges | Passed | |
| Main Menu statistics: Counter | Passed | |
| Main Menu statistics: Graphs | Redo | Daily Trend: it isn't clear |
| | Redo | Distribution: in the axe there is one 0 more |
| | Redo | Discharge duration: the graph isn't in centre at hours reference |
| | NOK | Battery temperature: without the sensor probe the measure is 0°C for long time |
| Main Menu Measurement | Passed | PCS Power |
| | Passed | AC Measures |
| | NOK | Battery Measures: time before charging/discharging not managed in the SAFT battery |
| | Passed | Sensor |
| Main Menu Alarm & Warning | Passed | Alarm |
| | Passed | Warning |
| Main Menu History log | Passed | |
| Main Menu Commands | - | Local command --> Disable |
| | Passed | Alarm reset |
| | Redo | Test Procedure: Led= KO; Ac contactor=loop; Fan Test=KO |

| | | |
|---|---|---|
| | Passed | Reset statistics |
| | Redo | System Configuration: if start the procedure isn't possible go out without complete the procedure |
| Main Menu set Preferences | Passed | Language |
| | Passed | Data and Time |
| | Passed | Buzzer |
| | Passed | Display |
| | Passed | Password |
| Main Menu set system configuration | Passed | |
| Main Menu set PCS settings | Passed | Country /Network code |
| | Redo | Connection parameters: only frequency threshold is possible modify |
| | Passed | AC interface protection |
| | Passed | Active Power |
| | Passed | Reactive power |
| Main Menu set Battery Setting | Passed | Battery type |
| | Passed | Battery parameters |
| | Passed | charge threshold |
| | NOK | Maintenance parameters : not displayed |
| | NOK | SOH calculation: not displayed |
| Main Menu set Option Device | NOK | Verify if the optional displayed are necessary |
| Main Menu set Connectivity | Passed | Peripherals |
| | Passed | Services |
| Main Menu Service firmware version | Passed | System |
| Main Menu Service SN | Passed | |
| Main Menu Communication Code | Passed | |
| Main Menu Upgrade FW | Passed | Upgrade HMI firmware |
| | Passed | Upgrade languages |

**Conclusion:** Most of the tests have been passed. **However some of them have to be replayed** during the final tests with the last firmware version.

- **Abnormal functioning tests**

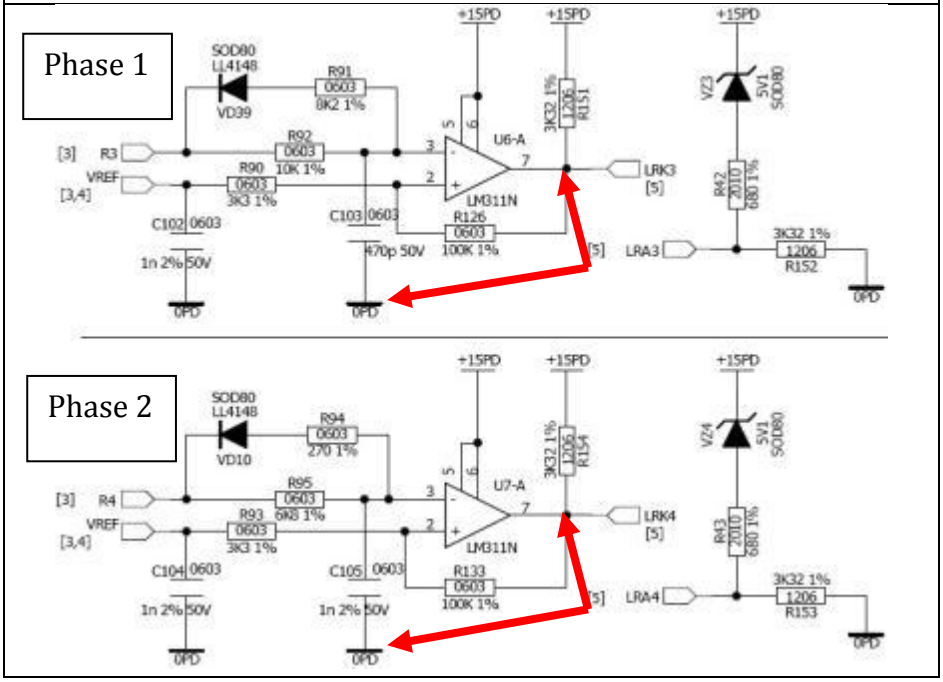
Date of the tests: October 2013.

The objective of these tests is to demonstrate, either on the AC side or the DC side in case of short circuits, that the SUNSYS PCS² is always safe and not the source of fire.

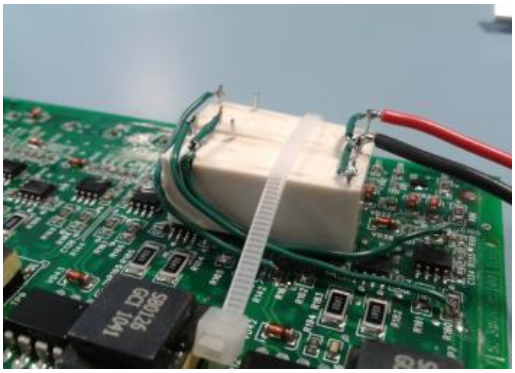
- **Short circuit on the IGBT electronic board:**

A short circuit is created on the IGBT (Insulated Gate Bipolar Transistor) electronic board (Phase 1 & 2) during discharging mode with a SOC equivalent to 50%.

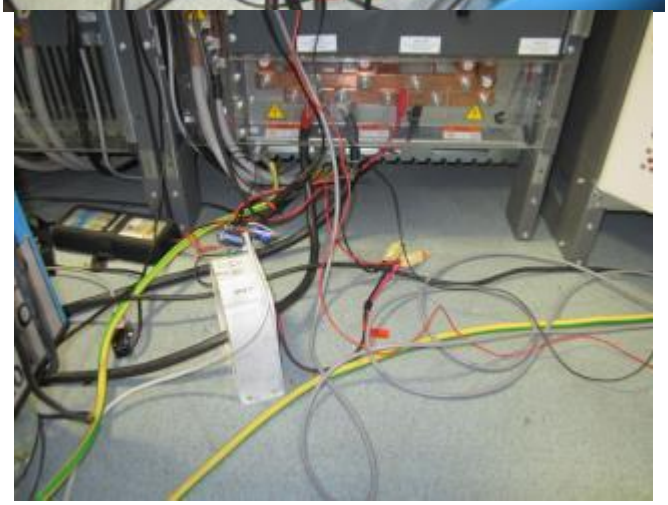
Internal diagram on the IGBT board and localisation of the short circuits.



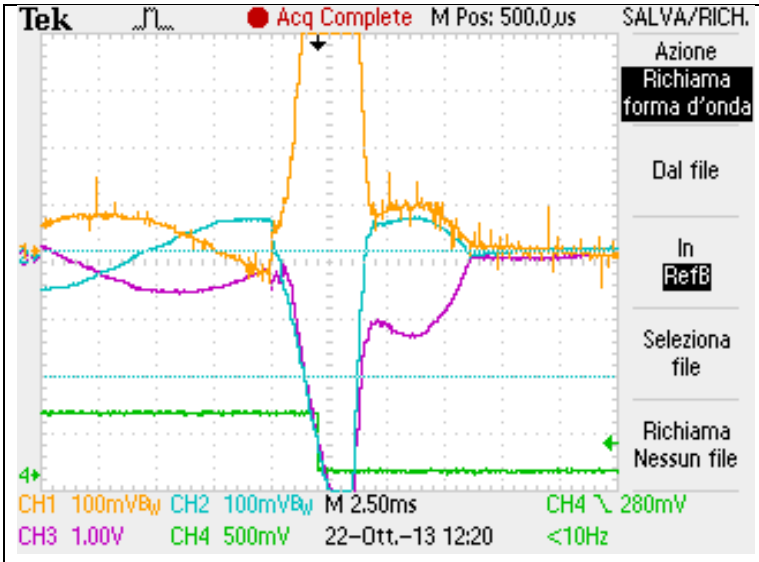

Short circuits are created thanks to relays mounted on the board:



Picture of the probes & sensors:



Hereafter the recorded curves during the short-circuit:




CH1= Output Current Phase 1 (100A/div)

CH2= Output Current Phase 2 (100A/div)

CH3= Output Current Phase 3 (100A/div)

CH4= Trigger TP8 (Enable Converter) (5V/div)

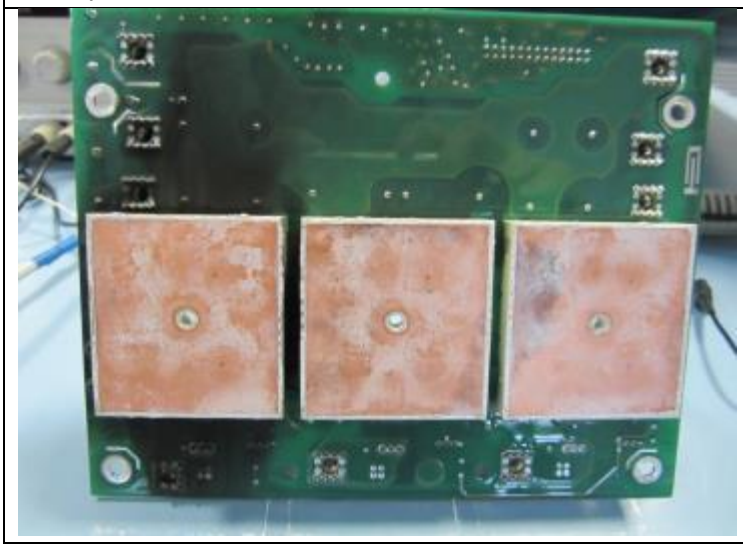
It can be seen the peak of the current at the time of the short circuit of the IGBT board.

When the short circuit appears, the SUNSYS PCS² asks immediately the opening of the DC contactor.

After the test, we can assess the following situation:

- The AC contactor is still operational.
- The DC contactor is still operational.
- The battery is still operational.
- The DC fuses are OK.
- The AC fuses of the phase 1 & 2 are blown but the AC fuses of the phase 3 are OK.

When we switch on the module, the alarm "AC voltage fault" appears".

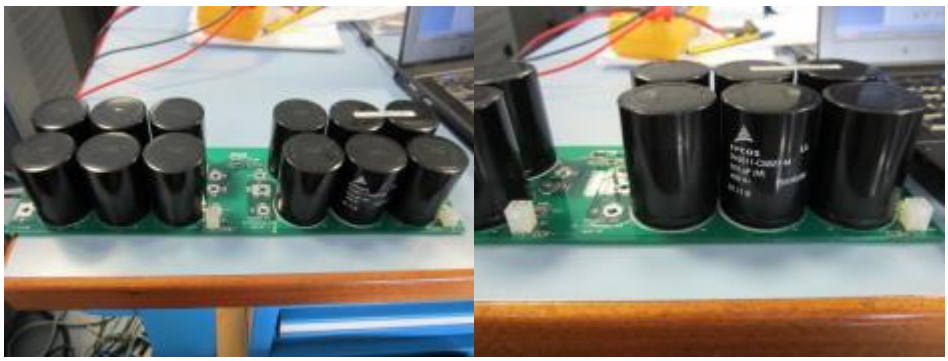
| IGBT power board after the test. | AC fuses of the phase 1 & 2 |
|---|---|
|  | |

After replacement of the faulty components, all the functionalities of the power module are recovered.

**Conclusion**: **The test has been succeeded.**

- **Short-circuit on the DC capacitors:**

A short circuit is created on the DC capacitors board during charging mode under 18,6A & 580VDC.



In order to analyse possible fire propagation, a gas fibre is applied on the SUNSYS PCS²:

State of the DC capacitors board after the test:

Unlike the previous test, the contactors opening are not operated during the short circuit.

However the battery fuses are not blown and the battery is still operational.

The AC contactor and fuses are also in a good health.

There is no trace on the gas fibre.

The only damage component is the DC capacitors board.

After replacement of the faulty components, all the functionalities of the power module are recovered.

**Conclusion**: **The test has been succeeded.**

- ## Conformity with the standard

Because the SUNSYS PCS² range is, in terms of hardware & firmware, the equivalent of the SUNSYS PV inverters range, its certification is inherited from it:

- CE marking.

- Safety TUV certification:
  - EN 62477,
  - EN 60950,
  - EN 62109-1,
  - EN 62109-2.

- EMC:
  - Electromagnetic Compatibility Directive,
  - EN 61000-3-11,
  - EN 61000-3-12,
  - EN 61000-6-2,
  - EN 61000-6-3.

- Grid codes:
  - CEI-021 (Italy LV)
  - CEI-016 (Italy MV)
  - VDE 0126-1-1.
  - VDE 0126-1-1/A1, VFR2013, VFR2014 (France LV)

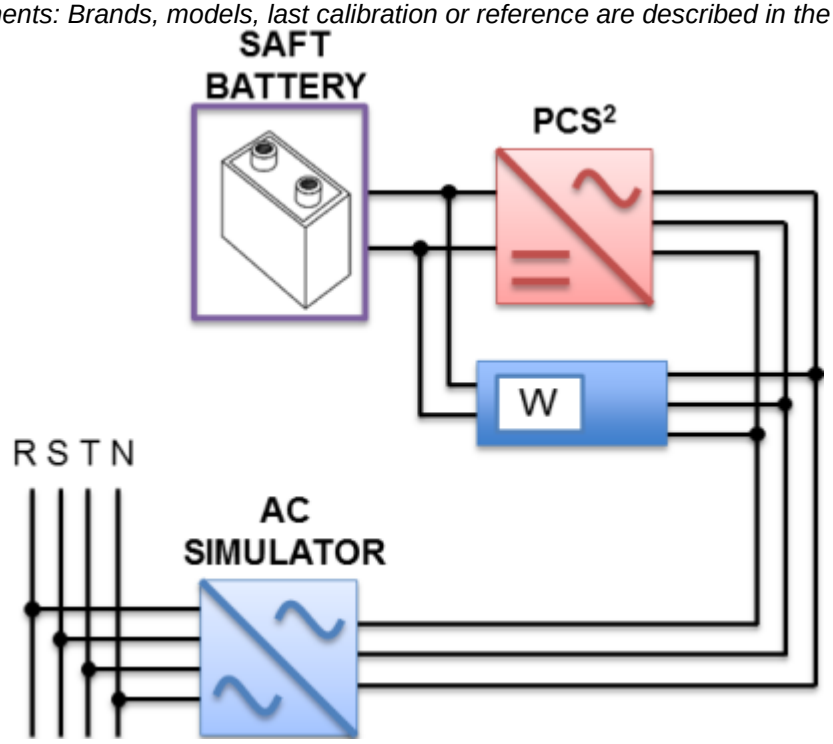
The certificates are available.In order to be compliant with a regional grid code, the dedicated parameters have to be properly set.

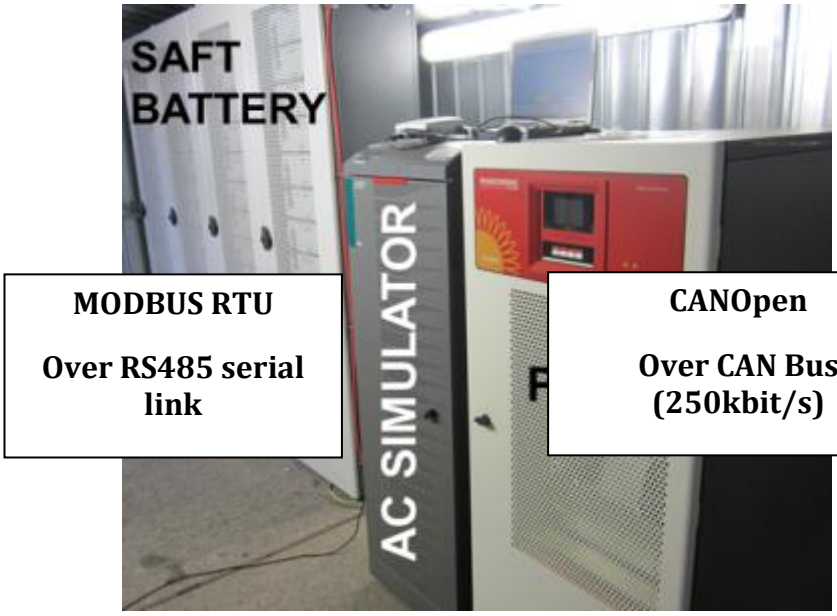
- **SUNSYS PCS² 33TR & SAFT Battery**
- **Tools**

In order to perform the tests described in the following paragraphs, SOCOMEC has built equipment composed of the following main components:

- A grid connection.
- A SAFT battery set (2 ESSU 53kWh + 2 BMM + 1 MBMM).
- An AC source simulator.
- A SUNSYS PCS² 33TR.
- Wattmeter (Yokogawa - WT3000).
- A CAN bus analyser (via PCAN Explorer).
- An Oscilloscope (DPO4054).

*(Details about these components: Brands, models, last calibration or reference are described in the tests reports).*






- **Communication**

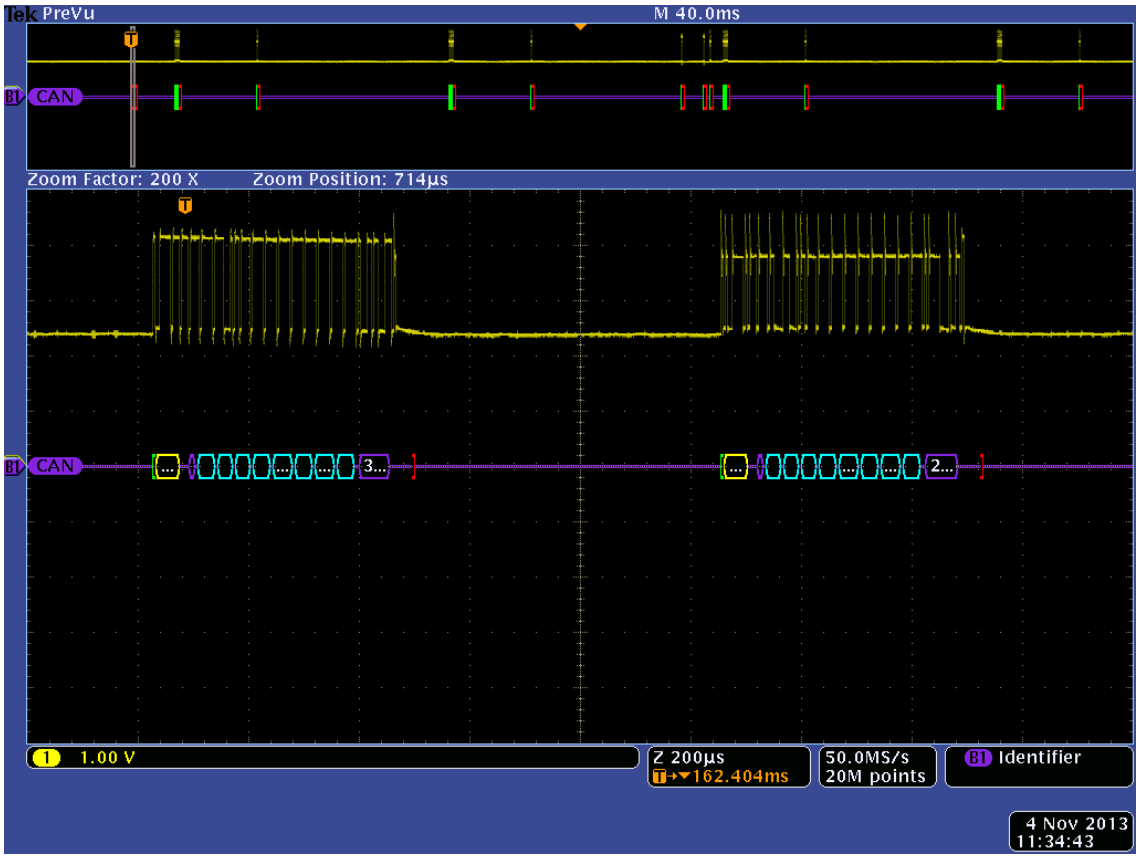
The communication link between SOCOMEC SUNSYS PCS² 33TR **HMI** and SAFT **MBMM** is possible using a **gateway** to translate different protocols.

SUNSYS PCS² supports the standard MODBUS RTU Application-layer protocol (Over RS485) while MBMM supports Standard CANOpen protocol (Over CAN bus).

- **CANOpen - Electrical Signal**

Date of the tests: November 2013.

The objective of this test is to verify whether electrical signals (CAN bus) are clean by observing with oscilloscope the timings, the edges status and the general levels.




**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*:
"M208_Battery_Protocol_Test.doc"

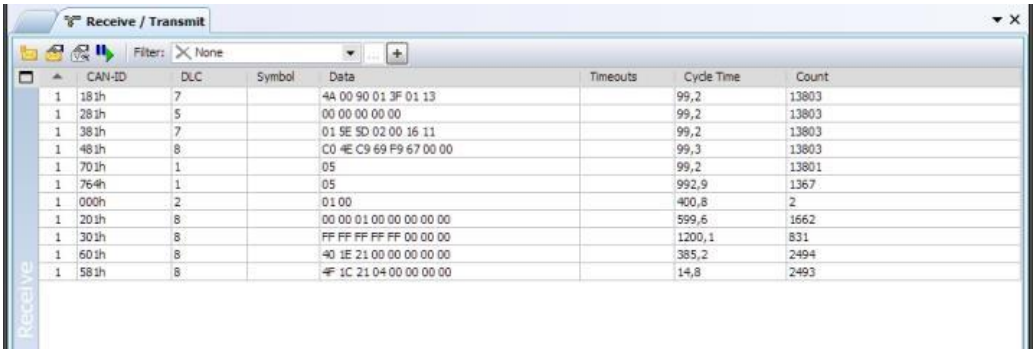
- **Monitor CANOpen Bus**

Date of the tests: November 2013.

The objective of this test is to verify **the timings & the completeness of exchanged data between the gateway and the MBMM** for the 2 types of CANOpen frames:

- **PDO** (Process Data Object): The Process Data Object protocol is used to process real time data (periodical transmission),
- **SDO** (Service Data Object): The SDO protocol is used for setting and for reading values (contextual transmission).

CANOpen frames have been monitored via PCAN Explorer:




| | CAN-ID | DLC | Symbol | Data | Timeouts | Cycle Time | Count |
|---|---|---|---|---|---|---|---|
| 1 | 181h | 7 | | 4A 00 90 01 3F 01 13 | | 99,2 | 13803 |
| 1 | 281h | 5 | | 00 00 00 00 00 | | 99,2 | 13803 |
| 1 | 381h | 7 | | 01 5E 5D 02 00 16 11 | | 99,2 | 13803 |
| 1 | 481h | 8 | | C0 4E C9 69 F9 67 00 00 | | 99,3 | 13803 |
| 1 | 701h | 1 | | 05 | | 99,2 | 13801 |
| 1 | 764h | 1 | | 05 | | 992,9 | 1367 |
| 1 | 000h | 2 | | 01 00 | | 400,8 | 2 |
| 1 | 201h | 8 | | 00 00 01 00 00 00 00 00 | | 599,6 | 1662 |
| 1 | 301h | 8 | | FF FF FF FF FF 00 00 00 | | 1200,1 | 831 |
| 1 | 601h | 8 | | 40 1E 21 00 00 00 00 00 | | 385,2 | 2494 |
| 1 | 581h | 8 | | 4F 1C 21 04 00 00 00 00 | | 14,8 | 2493 |

**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*:
"M208_Battery_Protocol_Test.doc"

- **Gateway Configuration**

  The gateway manufacturer provides software to set-up its gateway: Firmware Compositor.

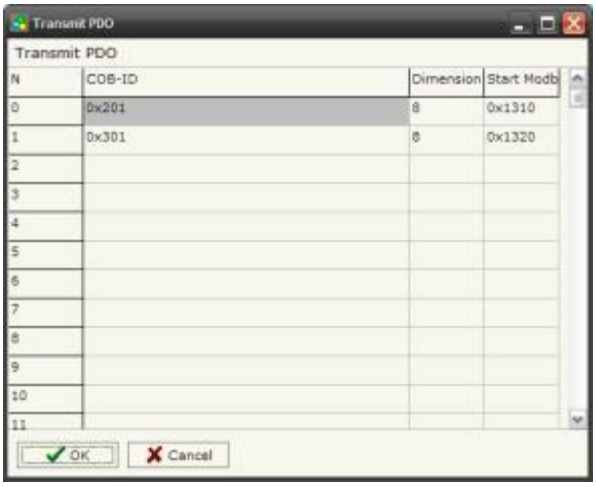
The most important points include the communication settings and the mapping between MODBUS and CANOpen TPDO/RPDO and TSDO/RSDO.

Communication Settings:

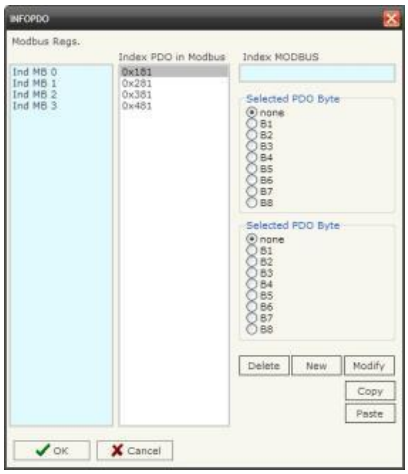
MODBUS side: Modbus RTU - RS485 Serial Interface – Baud rate 38400 8N1 – Dev. ID 100

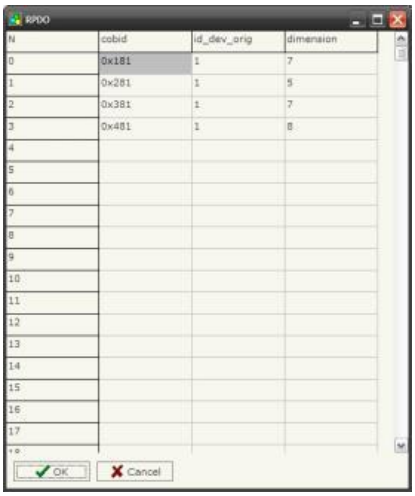
CANOpen side: Dev. ID 100 – Baud rate 250kbs

- **Mapping Transmit PDOs [HMI ➔ MBMM]:**

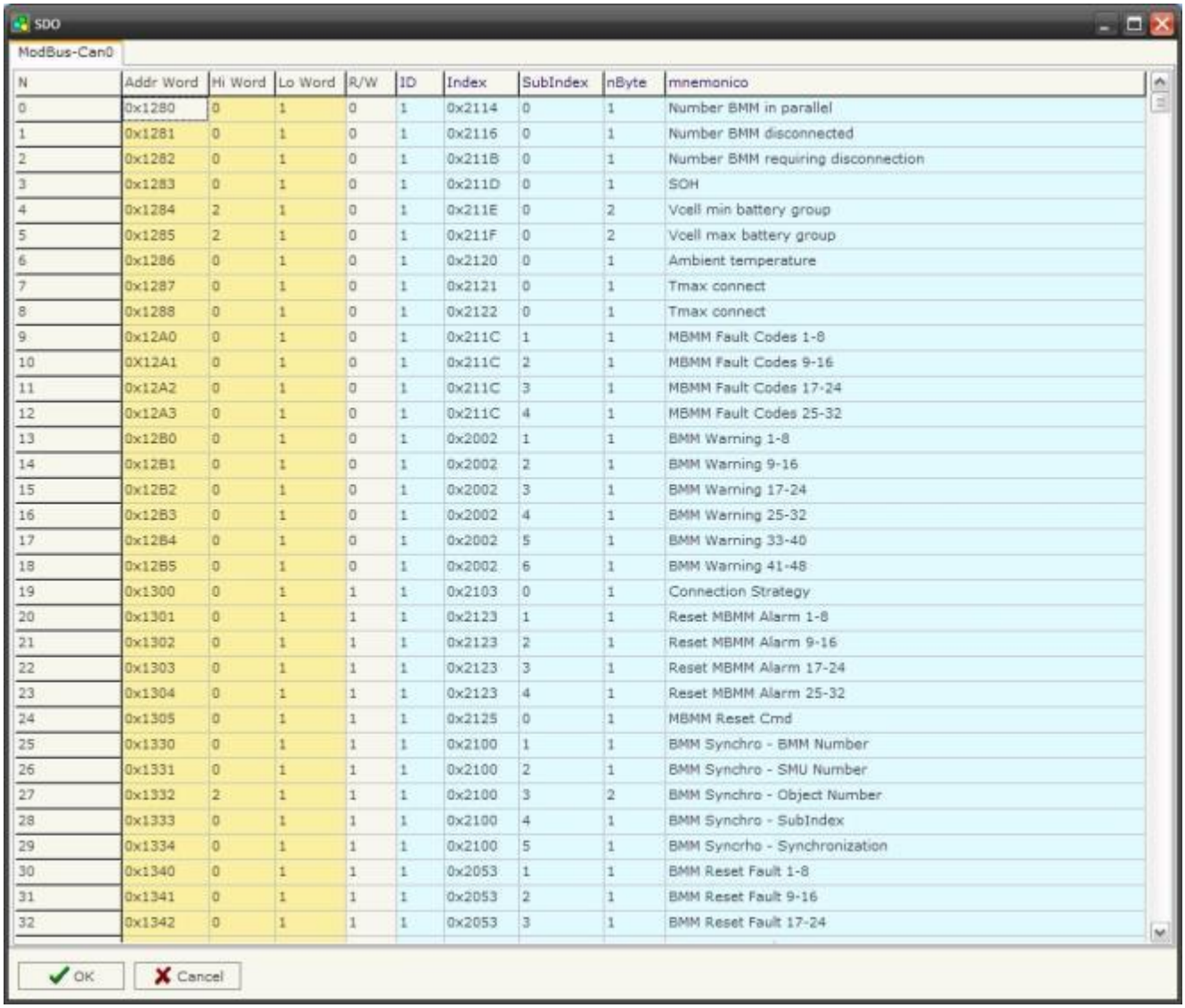



- **Mapping Receive PDOs [HMI ➔ MBMM]:**



- **Mapping SDOs [HMI ⇔ MBMM]:**




| N | Addr Word | Hi Word | Lo Word | R/W | ID | Index | SubIndex | nByte | mnemonico |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0x1280 | 0 | 1 | 0 | 1 | 0x2114 | 0 | 1 | Number BMM in parallel |
| 1 | 0x1281 | 0 | 1 | 0 | 1 | 0x2116 | 0 | 1 | Number BMM disconnected |
| 2 | 0x1282 | 0 | 1 | 0 | 1 | 0x211B | 0 | 1 | Number BMM requiring disconnection |
| 3 | 0x1283 | 0 | 1 | 0 | 1 | 0x211D | 0 | 1 | SOH |
| 4 | 0x1284 | 2 | 1 | 0 | 1 | 0x211E | 0 | 2 | Vcell min battery group |
| 5 | 0x1285 | 2 | 1 | 0 | 1 | 0x211F | 0 | 2 | Vcell max battery group |
| 6 | 0x1286 | 0 | 1 | 0 | 1 | 0x2120 | 0 | 1 | Ambient temperature |
| 7 | 0x1287 | 0 | 1 | 0 | 1 | 0x2121 | 0 | 1 | Tmax connect |
| 8 | 0x1288 | 0 | 1 | 0 | 1 | 0x2122 | 0 | 1 | Tmax connect |
| 9 | 0x12A0 | 0 | 1 | 0 | 1 | 0x211C | 1 | 1 | MBMM Fault Codes 1-8 |
| 10 | 0X12A1 | 0 | 1 | 0 | 1 | 0x211C | 2 | 1 | MBMM Fault Codes 9-16 |
| 11 | 0x12A2 | 0 | 1 | 0 | 1 | 0x211C | 3 | 1 | MBMM Fault Codes 17-24 |
| 12 | 0x12A3 | 0 | 1 | 0 | 1 | 0x211C | 4 | 1 | MBMM Fault Codes 25-32 |
| 13 | 0x12B0 | 0 | 1 | 0 | 1 | 0x2002 | 1 | 1 | BMM Warning 1-8 |
| 14 | 0x12B1 | 0 | 1 | 0 | 1 | 0x2002 | 2 | 1 | BMM Warning 9-16 |
| 15 | 0x12B2 | 0 | 1 | 0 | 1 | 0x2002 | 3 | 1 | BMM Warning 17-24 |
| 16 | 0x12B3 | 0 | 1 | 0 | 1 | 0x2002 | 4 | 1 | BMM Warning 25-32 |
| 17 | 0x12B4 | 0 | 1 | 0 | 1 | 0x2002 | 5 | 1 | BMM Warning 33-40 |
| 18 | 0x12B5 | 0 | 1 | 0 | 1 | 0x2002 | 6 | 1 | BMM Warning 41-48 |
| 19 | 0x1300 | 0 | 1 | 1 | 1 | 0x2103 | 0 | 1 | Connection Strategy |
| 20 | 0x1301 | 0 | 1 | 1 | 1 | 0x2123 | 1 | 1 | Reset MBMM Alarm 1-8 |
| 21 | 0x1302 | 0 | 1 | 1 | 1 | 0x2123 | 2 | 1 | Reset MBMM Alarm 9-16 |
| 22 | 0x1303 | 0 | 1 | 1 | 1 | 0x2123 | 3 | 1 | Reset MBMM Alarm 17-24 |
| 23 | 0x1304 | 0 | 1 | 1 | 1 | 0x2123 | 4 | 1 | Reset MBMM Alarm 25-32 |
| 24 | 0x1305 | 0 | 1 | 1 | 1 | 0x2125 | 0 | 1 | MBMM Reset Cmd |
| 25 | 0x1330 | 0 | 1 | 1 | 1 | 0x2100 | 1 | 1 | BMM Synchro - BMM Number |
| 26 | 0x1331 | 0 | 1 | 1 | 1 | 0x2100 | 2 | 1 | BMM Synchro - SMU Number |
| 27 | 0x1332 | 2 | 1 | 1 | 1 | 0x2100 | 3 | 2 | BMM Synchro - Object Number |
| 28 | 0x1333 | 0 | 1 | 1 | 1 | 0x2100 | 4 | 1 | BMM Synchro - SubIndex |
| 29 | 0x1334 | 0 | 1 | 1 | 1 | 0x2100 | 5 | 1 | BMM Syncrho - Synchronization |
| 30 | 0x1340 | 0 | 1 | 1 | 1 | 0x2053 | 1 | 1 | BMM Reset Fault 1-8 |
| 31 | 0x1341 | 0 | 1 | 1 | 1 | 0x2053 | 2 | 1 | BMM Reset Fault 9-16 |
| 32 | 0x1342 | 0 | 1 | 1 | 1 | 0x2053 | 3 | 1 | BMM Reset Fault 17-24 |

- **Monitor Modbus Protocol**

Date of the tests: November 2013.

The objective of this test is to verify the **completeness of exchanged data between the SUNSYS PCS² 33TR HMI and the gateway** for the 2 types of CANOpen frames:

HMI uses only 3 functionalities of Modbus Protocol:

- 03 (0x03) Read Holding Registers
- 06 (0x06) Write Single Register
- 16 (0x10) Write Multiple registers

Modbus protocol has been monitored via RS485.

The correct format of every command (received from or sent to Gateway) has been verified:

Example of MODBUS Protocol Monitor:

64 03 12 20 00 07 09 4F → HMI read Modbus Address 0x1220

64 03 0E 00 5D 00 00 00 00 00 00 00 00 00 15 00 10 17 4F

64 03 12 40 00 04 49 50 → HMI read Modbus Address 0x1240

64 03 08 4E C0 69 C9 00 00 00 00 EA 83

64 03 12 60 00 08 48 9F → HMI read Modbus Address 0x1260

64 03 10 00 12 00 00 00 00 00 00 00 00 00 00 00 00 00 24 90

**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*:
"M208_Battery_Protocol_Test.doc"

- **Verify congruence of data**

Date of the tests: November 2013.

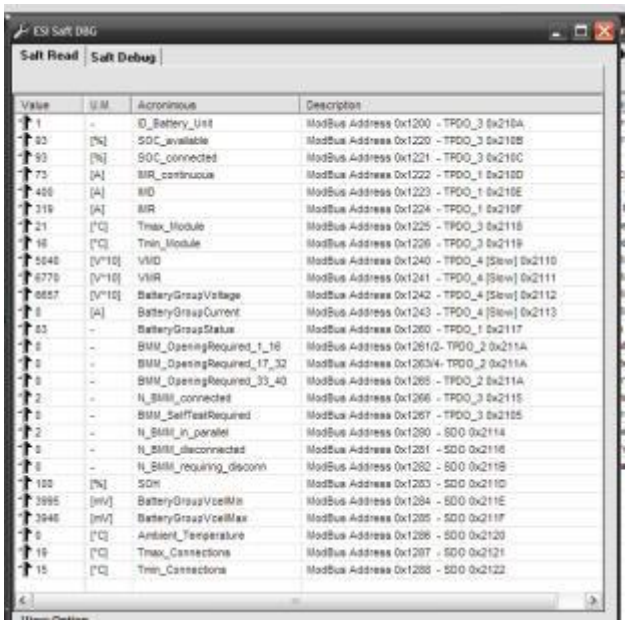
The congruence of data is verified in two different steps:

1. First it was checked whether the data received from Gateway (in Modbus Protocol) correspond with data monitored via the CANOpen Bus.

2. Second all received data (by HMI) were verified via Assist Software with particular attention to values and measurements units.

The written data (from HMI to MBMM) and the received data (from MBMM to HMI) have been validated with the same process.

These are the windows of Assist Software used to control all MBMM data during running:



It is important to note that this monitoring has been permanently used from November 2013 until now in order to sniff a huge quantity of frames and to detect some possible transmission fault.

A couple of faulty cases have been detected on the MBMM side and solved.

**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*:
"M208_Battery_Protocol_Test.doc"

- **State Machine**

Date of the tests: December 2013.

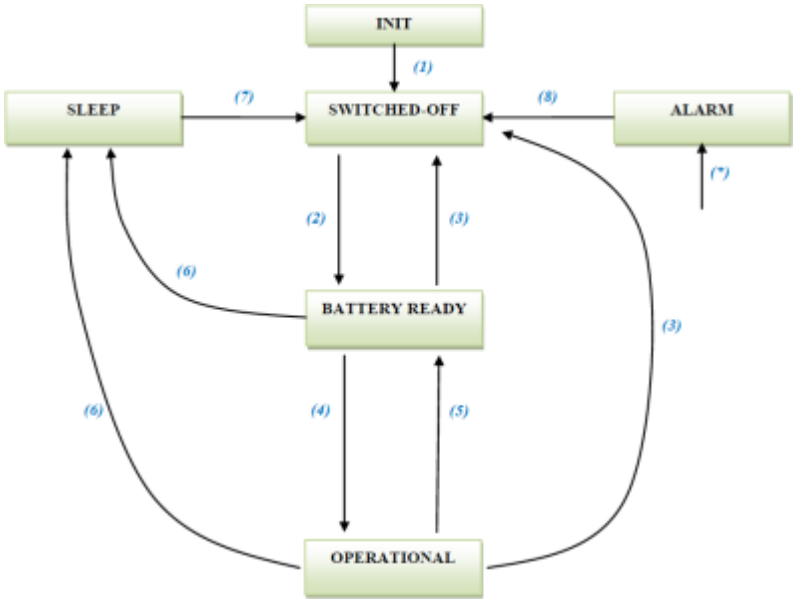
The objective of this test is to validate the logical sequences of the different state-machines.

- **Main State-Machine:**

The union of the SUNSYS PCS² and SAFT Battery is named Energy Conversion & Storage equipment (**ECSE**).

The **ECSE** is typically managed by an external Energy Manager System (**EMS**) controller (ERDF NEM & NBA in the Nice Grid Project), which has the task to define the rules for the energy exchanges between the storage system and the grid.

The **ECSE** implements the following main state-machine:




With the following state and transition conditions:

**INIT**:

During this state SUNSYS PCS² is not supplied. HMI and Converter Module are switched off.

***(1)*** At system power-up, the PCS automatically enters the SWITCHED-OFF State, from the INIT State.

**SWITCHED OFF**:

During this state, the DC and AC contactors are opened.

Only the HMI is supplied (by aux. AC).

It establishes the communication with the MBMM through the Gateway and verifies the State of the MBMM.

***(2)*** When EMS sends “Switch-On Command”, if MBMM is in the standby condition, HMI sends first the “Connection Strategy Command” and then the “Authorization to Close”.

After DC contactor is closed (SUNSYS PCS² modules are supplied by DC voltage) and the MBMM is in “Nominal” condition, the SUNSYS PCS² jumps to BATTERY READY State.

**BATTERY READY**:

During this state the DC contactor is closed and converter module switched on.

If all grid checks are successfully completed, SUNSYS PCS² informs the EMS that ECSE is ready to start.

***(3)*** In case of “Contactor Opening Required” on all BMMs or in case of “Switch-Off “command from EMS, the SUNSYS PCS sends the “Opening Command ” and goes back to SWITCHED OFF State.

***(4)*** When EMS sends this "Operation-mode Enable" command, the ECSE jumps to OPERATIONAL State.

***(6)*** In case of inactivity of the PCS (no set-point sent by EMS) during 30 minutes and low Battery SOC, the converter enters the SLEEP State.

**OPERATIONAL**:

During this state the DC contactor is closed, the AC contactor is closed and the SUNSYS PCS² is connected to the grid and starts operating according with the set-point sent by EMS.

***(3)*** In case of “Contactor Opening Required” on all BMM or in case of “Switch-Off “command from EMS, the SUNSYS PCS² sends the “Opening command ” and goes back to SWITCHED OFF State.

***(5)*** When EMS send the "Operation-mode Disable" command, ECSE jump to BATTERY READY State.

***(6)*** In case of inactivity of the SUNSYS PCS² (any set-point sent by EMS) for 30 minutes and low Battery SOC, the converter enters the SLEEP State.

**SLEEP**:

During this state DC and AC contactors are opened and the PCS is disconnected from the grid.

***(7)*** SUNSYS PCS² returns in SWITCHED OFF State, after the EMS resets the SLEEP State.

**ALARM**:

During this state only HMI is supplied (by aux. AC), while Converter Module is switched off (the Battery is always disconnected).

***(8)*** If EMS sends "Alarm Reset", HMI tries to reset the alarms (using “MBMM Faults Reset” or “BMM Faults Reset” procedures). If procedure of reset can be performed, then PCS jump to SWITCHED_OFF State, otherwise remains in this state.

***(*)*** *Active Alarm*:

In case of active alarm, the system enters the ALARM State from any other state.

Alarm can be generated by the SUNSYS PCS² or by the Battery:

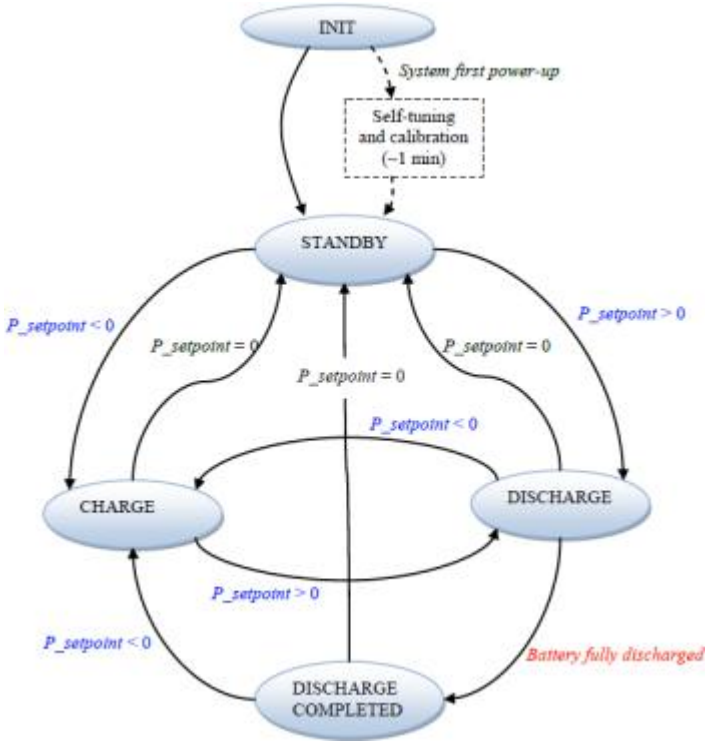
SUNSYS PCS² Alarm can be activated from HMI or from the Convert Module.

Battery Alarm is activated only in case of MBMM in Safe Mode. This is considered as a critical condition.

All other alerts reported by the SAFT batteries (without Safe Mode active) are in turn reported by the SUNSYS PCS², but do not cause a system stop.

- **OPERATIONAL State-Machine:**

In this mode, active and reactive power exchanged with the grid can be dynamically controlled by the EMS via FCU, through *P_setpoint* & *Q_setpoint*. The following state-machine can be taken as a reference:




Only at first power-on of the SUNSYS PCS², a self-tuning/calibration process is performed by the machine. This operation can take about 1 minute. When all checks are successfully completed, SUNSYS PCS² advises the EMS that ECSE is ready to start and waits in standby condition.

The PCS updates continuously some information about its state for the EMS, useful to know if it is possible charge or discharge battery:

- Flag "*Battery can be charged*" ➔ This flag is active when SUNSYS PCS² receives from MBMM values of :
  - IMR > 0A
  - IMR_C > 0A

When both values go to zero this flag is deactivated.

- Flag "Battery can be discharged" ➔ This flag is active when SUNSYS PCS² receives from MBMM values of :
  - IMD > 0A

When value goes to zero this flag is deactivated.

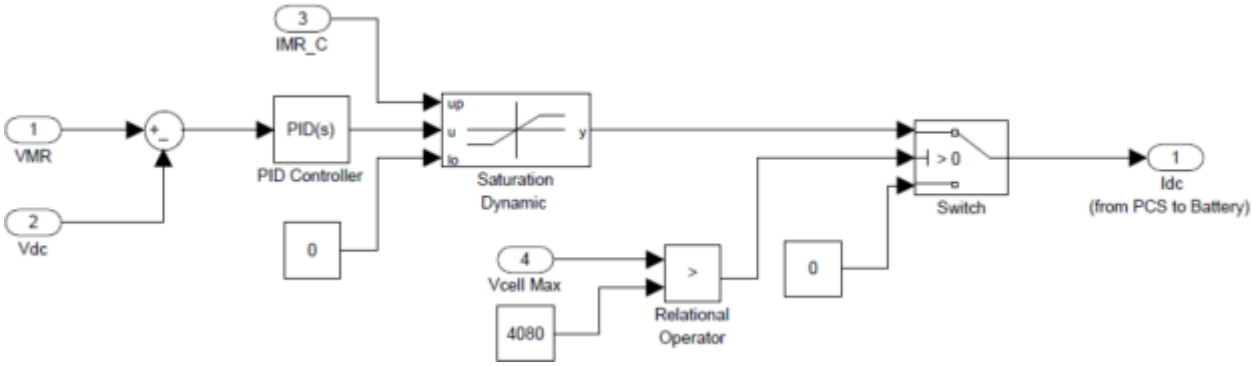
- Flag “Battery fully discharged” ➔ This flag is active when SUNSYS PCS² receives from MBMM values of :
  - SOC = 0% (20% in real situation)
  - Battery Group Voltage ≤ VMD
  - Vcell Min Battery Group ≤ 2070mV

When this flag is active the converter module stops and remains in this condition until a new charge set point.

During CHARGE (with *P_setpoint* < 0) or DISCHARGE (with *P_setpoint* > 0) the SUNSYS PCS² continuously verifies if the set point received from EMS requires a value of current above the recommended current limit of the MBMM. In any case, the SUNSYS PCS² limits the current to IMR_C or IMD values.

- CHARGE: In this phase, the SUNSYS PCS² uses VMR as voltage reference and limits its current to IMR_C.

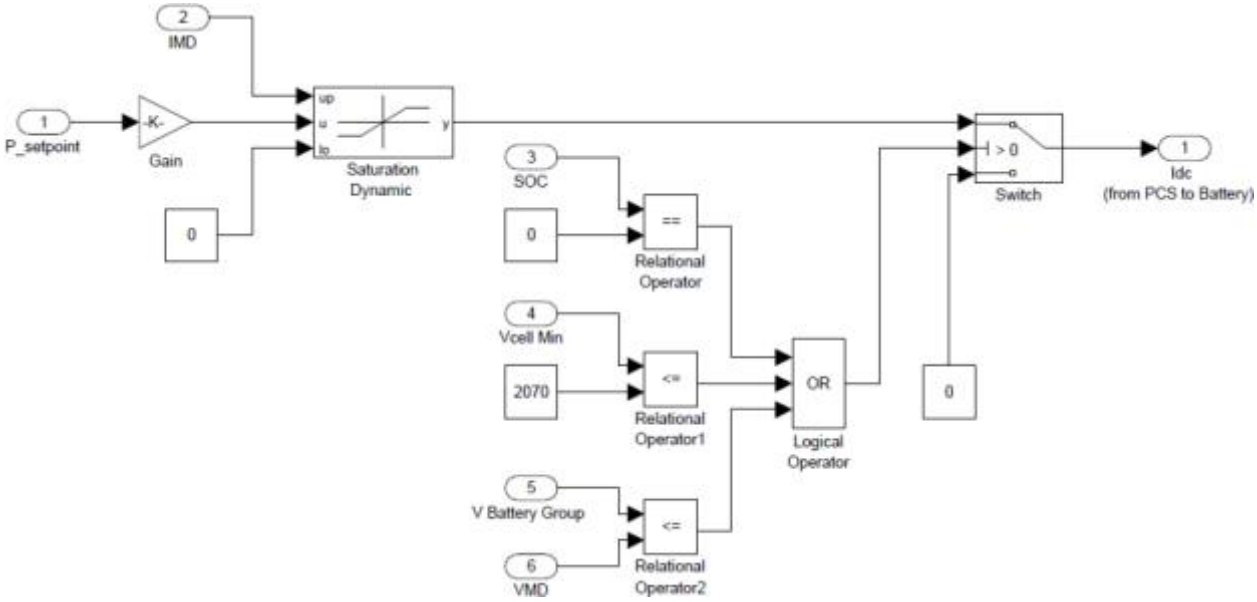
There is also a control to limit the “Vcell Max Battery Group”: SUNSYS PCS² verifies it doesn’t overcome value of 4080mV. If it happens *P_setpoint* is forced to zero (stops CHARGE) until Vcell Max returns under this critical value. This situation can happen when battery is quite unbalanced: in this case it’s possible to have low values of SOC and “Battery Group Voltage”, but a high value of “Vcell Max Battery Group”.



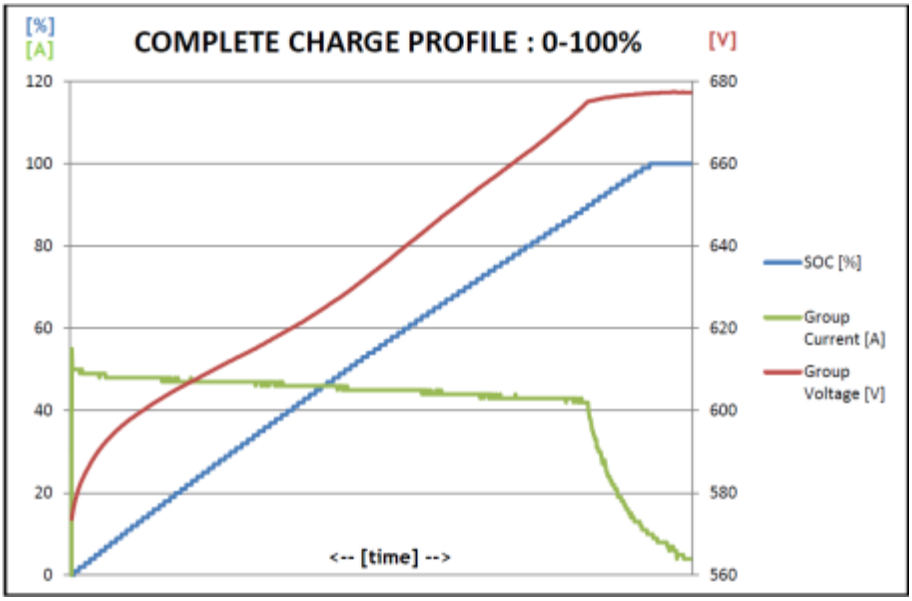

- DISCHARGE: at the end of discharge, the SUNSYS PCS² automatically stops operating if at least one of these situations is verified:
  - SOC = 0% (20% in real situation)
  - Battery Group Voltage ≤ VMD
  - Vcell Min Battery Group ≤ 2070mV

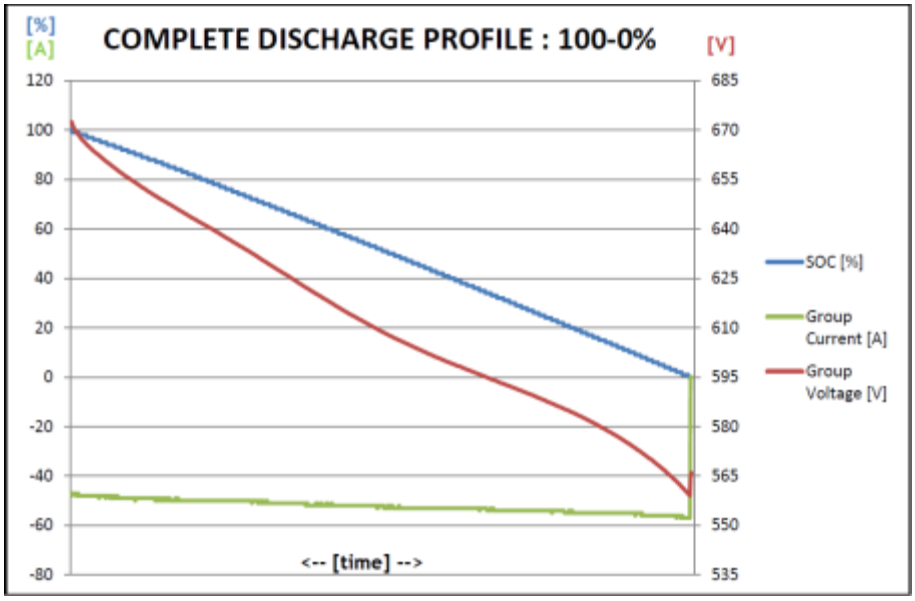
At the same moment, the flag of “Fully Discharged” is activated.

With “Vcell Min Battery Group” ≤ 2070mV the SUNSYS PCS² stops discharge even if the value of Battery SOC is not equal to zero, in order to avoid alarm of minimum cell voltage.




Samples of charge & discharge sequence:






**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*:
"SOCOMEC_PCS_Saft_Battery_REV_01.pdf"

- **Capabilities**

Date of the tests: January 2014.

The objective of this test is to verify the battery and converter Behaviour & Capabilities during the phase of charge and discharge.

- **DISCHARGE TEST AT NOMINAL POWER**

During discharge, the SMU sends data on the CAN bus to the BMM.

Note that the SMU sends data either on BMM request or periodically.

The BMM collects all the data of all the SMU boards composing the battery system and manage alarms to the customer

The table below gives the discharge current limits (continuous and pulse 5 seconds) versus temperature.

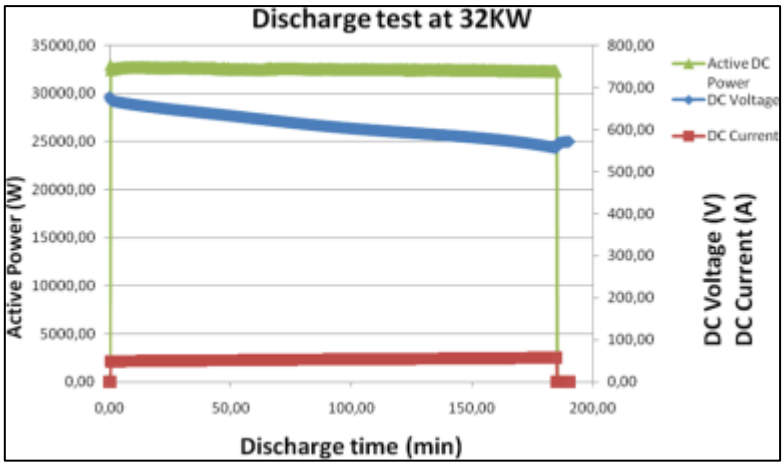
| *T [°C]* | -30 | -25 | -20 | -10 | 0 | 10 | 20 | 45 | 50 | 55 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *IMD_C [A]* | 0 | 116 | 142 | 200 | 200 | 200 | 200 | 200 | 200 | 150 | 0 |
| *IMD [A] 5 sec pulse* | 0 | 232 | 286 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 0 |

**Table 4 : IMD_C and IMD depending on the temperature**

**When a full discharge has been performed, it is recommended to charge the module immediately (within 1 day) or, if not possible, to switch off the BMM in order to stop the internal consumption of battery electronics.**

**If one cell is over-discharged (<2V), the battery is out of order and SAFT shall be contacted. For lithium-ion technology, when the cell voltage reaches a very low value, the battery may no longer be operational. The alarm value includes tolerance, but under this limit the battery life cannot be guaranteed.**

Before discharging the battery cabinet, it was fully charged (SOC = 100%).

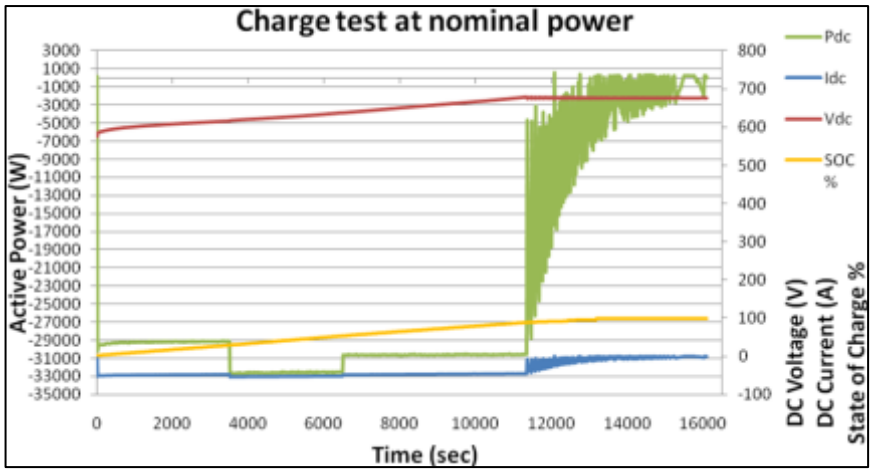



Time of discharge : 3 hours.

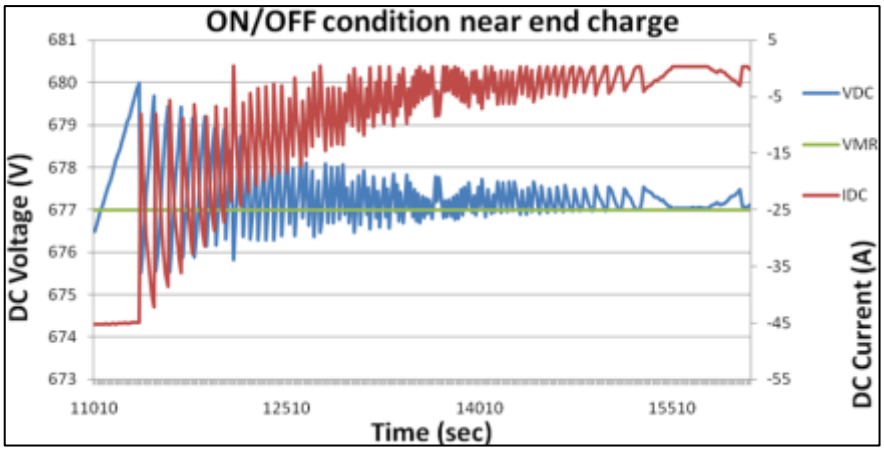
- **DISCHARGE TEST AT NOMINAL POWER**

After discharge test, it is necessary to recharge the batteries immediately to avoid the unbalance cells problems.

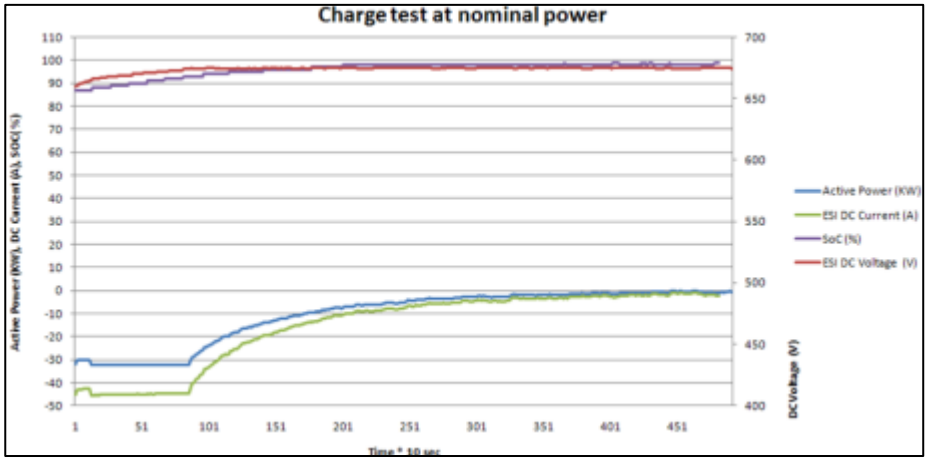
The charge is done at constant power; as shows in the picture below; the first period of charge is done with 29kW and after one hours it was increase at maximum possible of 33kW (for 30 minutes the converter works in overload). After overload time, the power was decrease at 31kW. Time of charge is ~4.5 hours.




When the DC voltage is about 677V (VMR= Max Voltage Recharge), for the final part of recharge, the current is limited and there is the on/off effect. This effect should be solved with a new firmware version.




The picture hereafter shows the recharge test after firmware correction. Close to the charge end the on/off effect has been corrected.

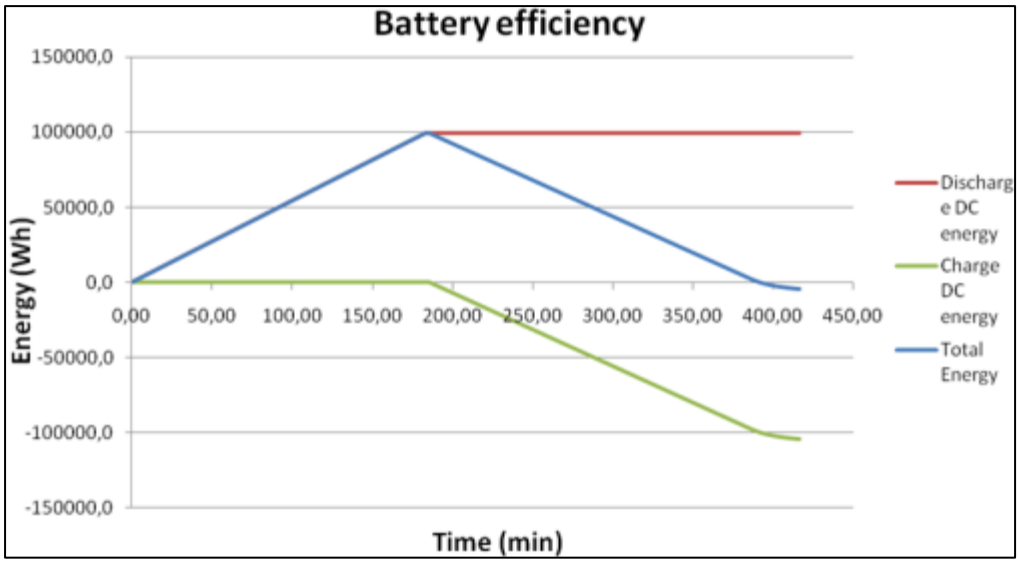



- **Battery efficiency:**

The efficiency is measured after a test of charge (0 ➔ 100kWh) and discharge (100kWh ➔ 0kWh) at nominal power.

The discharge DC energy measured was: 99245Wh (after 3 hours)

The charge DC energy measured was: 103834Wh (after 4 hours)

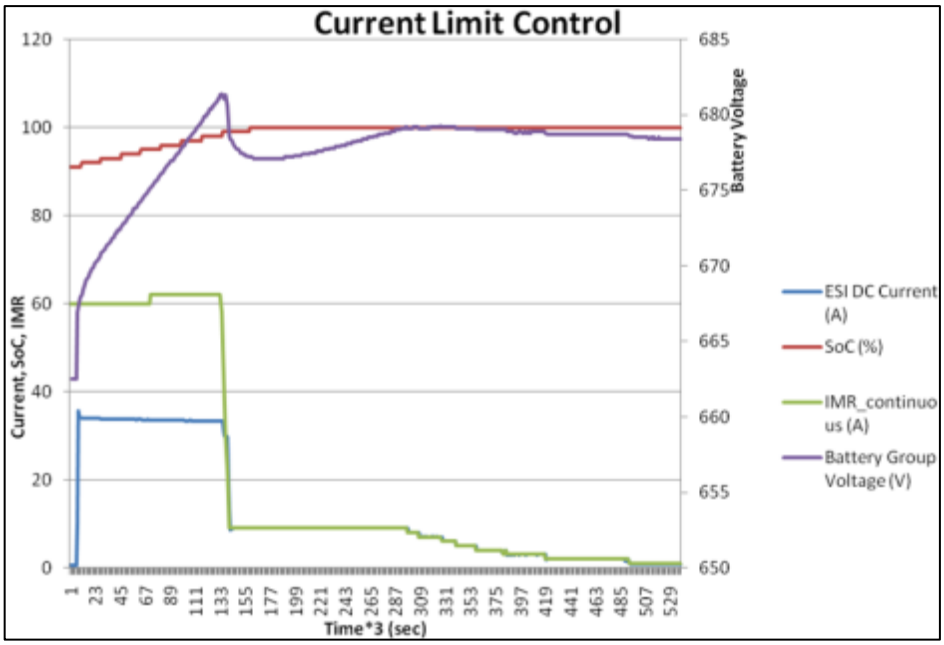



The battery efficiency is: 95.58%

- **Converter current limitation according to MBMM limit:**

To do the test it was necessary to disable the “Battery Vcell max “control and “Battery Group Voltage” by firmware. The test is done during the recharge condition with 75% Pn.

The IMR default is 60A, but with only one module (setting at 75%Pn) the max current is 35A.

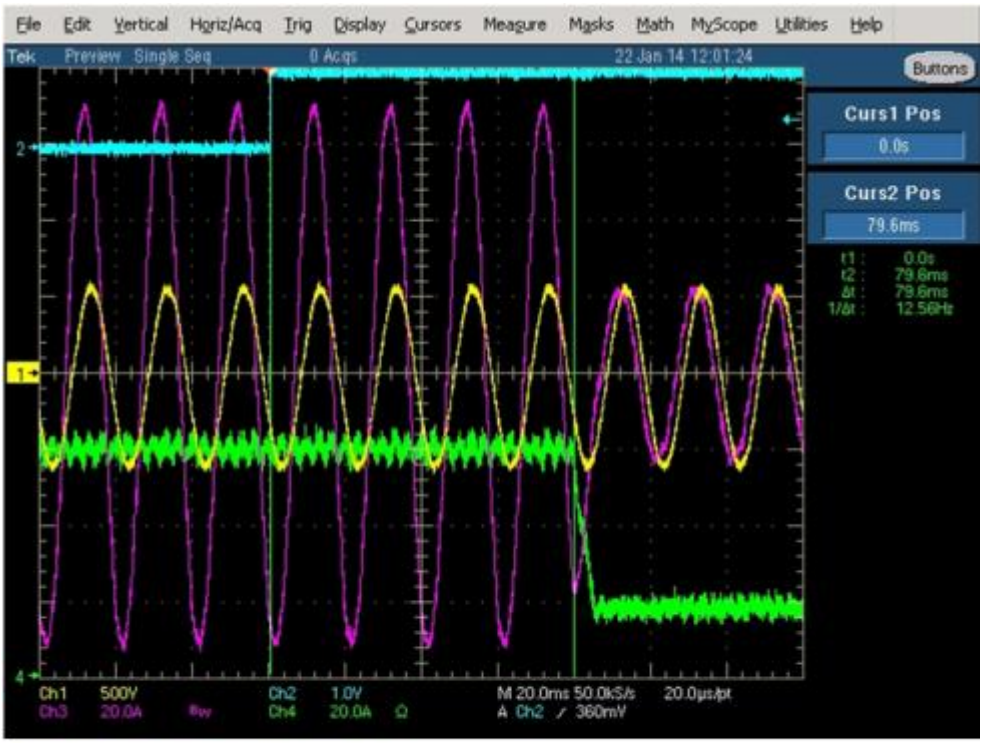


The test is passed because the battery current (IMR_continuous) is limited from the MBMM, if the voltage control is faulty.

- **Measure the time from the MBMM limitation to the real current reduction :**
  - Set point limitation during battery discharge:

In the picture below, it is possible to see the time from the moment when HMI recognizes the change of current limit to the moment when the current is limited (80ms).

Every 400ms HMI received from Gateway updated current measures, so the maximum delay, to recognize a setting modification, is 400ms so the maximum delay to have the real current modification is 400 + 80ms.




IMD: from 400A(default) to 20A (new limit) → from 36KW to 12KW

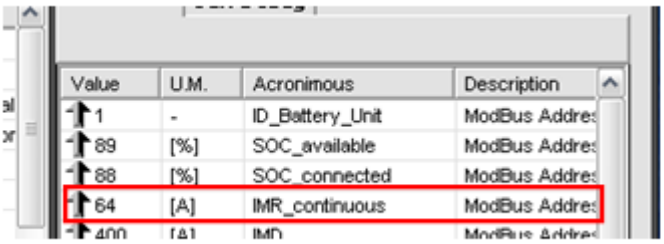
CH1= 500V/div Mains
CH3= 20A/div Mains Current
CH2= Command Trigger (by assist)
CH4=20A/div Battery current

- Set point limitation during battery charge:

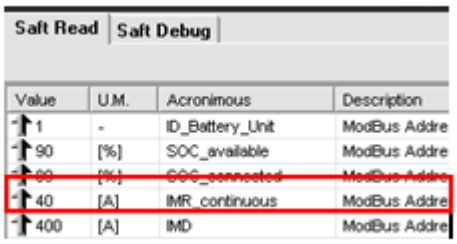
In the first picture the recharge current limit (IMR_continous) is that imposed from MBMM (64A). IMR_continous is set to a new value of 20A.

In the oscilloscope screen shoot, it is possible to analyse this variation of set point.

The delay time is the same as the previous test.

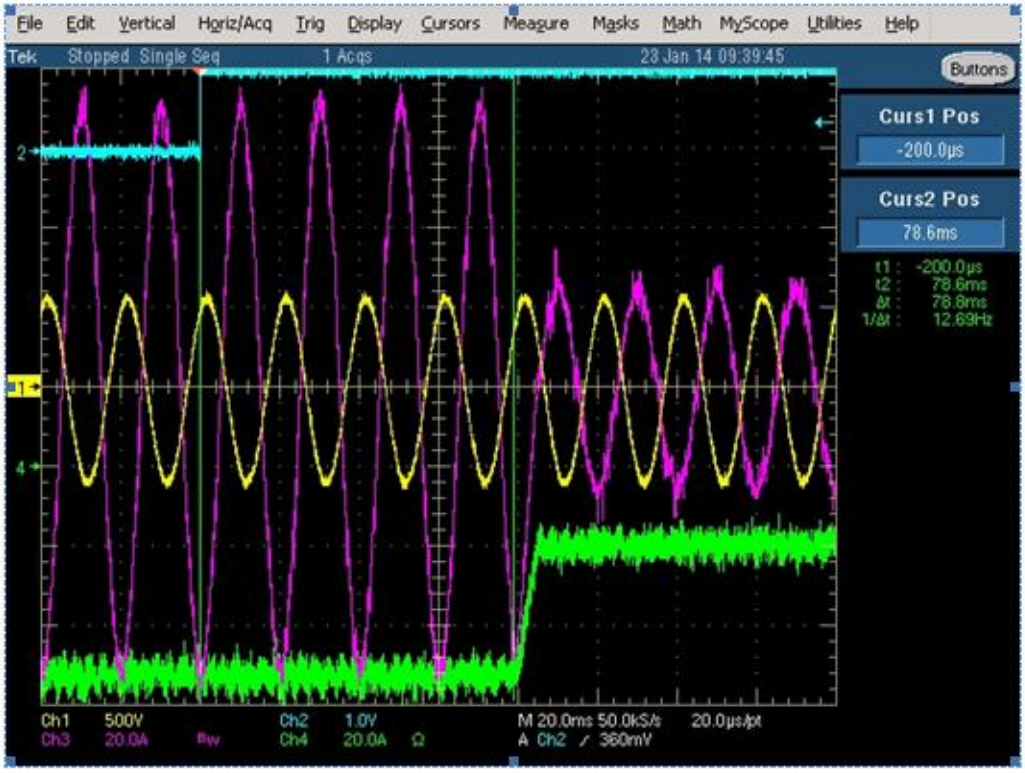


| Value | U.M. | Acronimous | Description |
|---|---|---|---|
| 1 | - | ID_Battery_Unit | ModBus Addres |
| 89 | [%] | SOC_available | ModBus Addres |
| 88 | [%] | SOC_connected | ModBus Addres |
| 64 | [A] | IMR_continuous | ModBus Addres |
| 400 | [A] | IMD | ModBus Addres |



Saft Read | Saft Debug

| Value | U.M. | Acronimous | Description |
|---|---|---|---|
| 1 | - | ID_Battery_Unit | ModBus Addre |
| 90 | [%] | SOC_available | ModBus Addre |
| 89 | [%] | SOC_connected | ModBus Addre |
| 40 | [A] | IMR_continuous | ModBus Addre |
| 400 | [A] | IMD | ModBus Addre |




IMR_continuous: from 64A(default) to 20A (new limit) → from 36KW to 12KW

**CH1= 500V/div Mains**
**CH2= Command Trigger (by assist)**
**CH3= 20A/div Mains Current**
**CH4=20A/div Battery current**

- **Measure the time from the MBMM limitation to the real voltage reduction:**
  - Set point limitation during battery discharge:

The VMD is set to higher value (670V) than the measure of battery voltage (663,3V).

The converter reduces the power in 80ms

| | | | |
|---|---|---|---|
| 319 | [A] | IMR | ModB |
| 18 | [°C] | Tmax_Module | ModB |
| 16 | [°C] | Tmin_Module | ModB |
| 6700 | [V*10] | VMD | ModB |
| 6770 | [V*10] | VMR | ModB |
| 6633 | [V*10] | BatteryGroupVoltage | ModB |
| 0 | [A] | BatteryGroupCurrent | ModB |

Test at Pn=36Kw

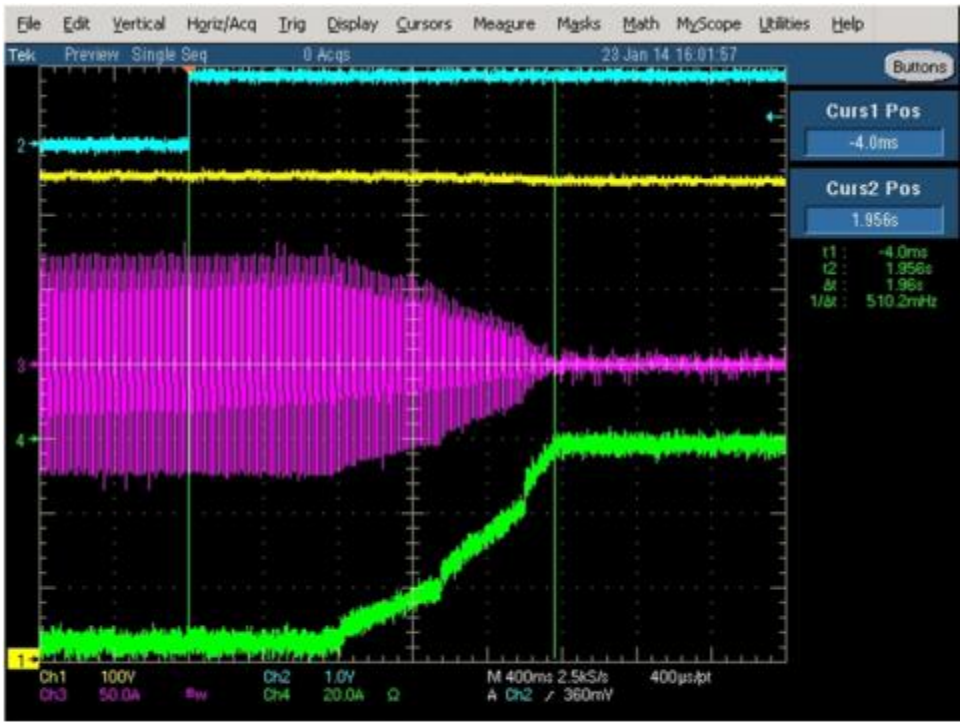
CH1= 100V/div Battery Voltage CH2= Command Trigger (by assist)
CH3= 50A/div Mains Current CH4=20A/div Battery current

- Set point limitation during battery charge:

The VMR is set to lower value (550V) than the measure of battery voltage (665V).

The converter reduces the power in 2000ms from the trigger.

| | | | |
|---|---|---|---|
| 18 | [°C] | Tmax_Module | M |
| 16 | [°C] | Tmin_Module | M |
| 5040 | [V*10] | VMD | M |
| 5500 | [V*10] | VMR | M |
| 6650 | [V*10] | BatteryGroupVoltage | M |
| 0 | [A] | BatteryGroupCurrent | M |




est at Pn=36Kw Pn→0

CH1= 100V/div Battery Voltage CH2= Command Trigger (by assist)
CH3= 50A/div Mains Current CH4=20A/div Battery current

- **STATIC MEASURES PRECISION**

On tables hereafter are reported the accuracy of the measures made during the cycles of charge and discharge. The accuracy is respected at the full scale of measure:

| Discharge test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wattmeter Measure | | | | Error % | | | | Converter Measure | | |
| Vdc(V) | Idc(A) | P(W) | | ΔV \| 1kV | ΔI \| 80A | ΔP \| 30kW | | Active Power (kW) | PCS² DC Voltage (V) | PCS² DC Current (A) |
| 674,26 | 3,40 | 2290,84 | | 0,13% | -0,18% | -0,31% | | 2,38 | 673,00 | 3,54 |
| 674,22 | 3,41 | 2299,56 | | 0,12% | -0,17% | -0,30% | | 2,39 | 673,00 | 3,55 |
| 674,17 | 3,41 | 2301,01 | | 0,12% | -0,16% | -0,27% | | 2,38 | 673,00 | 3,54 |
| 674,13 | 3,40 | 2294,45 | | 0,11% | -0,03% | -0,05% | | 2,31 | 673,00 | 3,43 |
| 674,09 | 3,42 | 2304,02 | | 0,11% | 0,00% | 0,01% | | 2,30 | 673,00 | 3,42 |
| 674,05 | 3,41 | 2300,97 | | 0,10% | -0,02% | -0,02% | | 2,31 | 673,00 | 3,43 |
| 674,01 | 3,41 | 2301,17 | | 0,10% | -0,02% | -0,02% | | 2,31 | 673,00 | 3,43 |
| 671,50 | 15,65 | 10509,40 | | 0,05% | -0,27% | -0,46% | | 10,65 | 671,00 | 15,87 |
| 671,34 | 15,69 | 10533,80 | | 0,03% | 0,01% | 0,04% | | 10,52 | 671,00 | 15,68 |
| 671,20 | 15,75 | 10569,60 | | 0,12% | 0,11% | 0,26% | | 10,49 | 670,00 | 15,66 |
| 671,08 | 15,69 | 10530,50 | | 0,11% | -0,03% | -0,01% | | 10,53 | 670,00 | 15,72 |
| 670,95 | 15,69 | 10529,00 | | 0,10% | -0,01% | 0,03% | | 10,52 | 670,00 | 15,70 |
| 670,83 | 15,69 | 10526,40 | | 0,08% | -0,10% | -0,13% | | 10,57 | 670,00 | 15,77 |
| 667,42 | 30,63 | 20440,50 | | 0,04% | -0,14% | -0,21% | | 20,50 | 667,00 | 30,74 |
| 663,78 | 45,95 | 30503,70 | | 0,08% | -1,27% | -2,12% | | 31,14 | 663,00 | 46,97 |
| 663,46 | 45,89 | 30448,30 | | 0,05% | -0,06% | -0,03% | | 30,46 | 663,00 | 45,94 |
| 663,14 | 46,01 | 30512,70 | | 0,11% | 0,12% | 0,38% | | 30,40 | 662,00 | 45,92 |
| 662,85 | 46,00 | 30492,90 | | 0,08% | 0,05% | 0,22% | | 30,43 | 662,00 | 45,96 |
| 662,56 | 46,01 | 30482,40 | | 0,06% | 0,00% | 0,08% | | 30,46 | 662,00 | 46,01 |
| 662,27 | 46,16 | 30567,90 | | 0,03% | 0,15% | 0,30% | | 30,48 | 662,00 | 46,04 |
| 659,47 | 55,56 | 36640,60 | | 0,05% | -0,01% | 0,07% | | 36,62 | 659,00 | 55,57 |

| Charge test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wattmeter Measure | | | | Error % | | | | Converter Measure | |
| Vdc(V) | Idc(A) | P(W) | | ΔV \| 1kV | ΔI \| 80A | ΔP \| 30kW | Active Power (kW) | PCS² DC Voltage (V) | PCS² DC Current (A) |
| 663 | -48,94 | -32428,70 | | 0,36% | 0,42% | 0,16% | -32,47552 | 659 | -49,28 |
| 663 | -48,97 | -32484,70 | | 0,24% | 0,18% | -0,08% | -32,46171 | 661 | -49,11 |
| 664 | -48,80 | -32405,00 | | 0,21% | 0,10% | -0,15% | -32,35856 | 662 | -48,88 |
| 665 | -48,88 | -32490,30 | | 0,27% | 0,12% | -0,22% | -32,42476 | 662 | -48,98 |
| 665 | -48,92 | -32539,00 | | 0,22% | -0,10% | -0,53% | -32,38092 | 663 | -48,84 |
| 666 | -48,74 | -32441,20 | | 0,16% | 0,12% | -0,04% | -32,42976 | 664 | -48,84 |
| 666 | -48,67 | -32409,50 | | 0,19% | 0,18% | 0,00% | -32,40984 | 664 | -48,81 |
| 666 | -40,91 | -27232,50 | | 0,16% | -0,26% | -0,67% | -27,03144 | 664 | -40,71 |
| 666 | -40,84 | -27190,20 | | 0,18% | 0,04% | -0,18% | -27,13768 | 664 | -40,87 |
| 666 | -40,80 | -27170,20 | | 0,20% | -0,01% | -0,29% | -27,08456 | 664 | -40,79 |
| 666 | -40,93 | -27267,30 | | 0,12% | -0,21% | -0,54% | -27,1054 | 665 | -40,76 |
| 666 | -40,73 | -27141,40 | | 0,13% | 0,03% | -0,12% | -27,1054 | 665 | -40,76 |
| 667 | -40,75 | -27163,40 | | 0,15% | -0,01% | -0,22% | -27,09875 | 665 | -40,75 |
| 667 | -40,79 | -27193,80 | | 0,17% | -0,04% | -0,29% | -27,1054 | 665 | -40,76 |
| 667 | -40,92 | -27286,30 | | 0,09% | -0,10% | -0,29% | -27,19944 | 666 | -40,84 |
| 665 | -27,42 | -18235,60 | | 0,20% | -0,51% | -1,09% | -17,90763 | 663 | -27,01 |
| 665 | -27,36 | -18198,30 | | 0,11% | -0,07% | -0,21% | -18,13384 | 664 | -27,31 |
| 665 | -27,35 | -18187,70 | | 0,21% | -0,07% | -0,31% | -18,09327 | 663 | -27,29 |
| 665 | -27,36 | -18198,40 | | 0,22% | -0,04% | -0,26% | -18,11979 | 663 | -27,33 |
| 665 | -27,34 | -18189,40 | | 0,22% | -0,04% | -0,28% | -18,10653 | 663 | -27,31 |
| 665 | -27,30 | -18163,10 | | 0,13% | 0,00% | -0,12% | -18,1272 | 664 | -27,3 |
| 665 | -27,48 | -18280,70 | | 0,14% | -0,16% | -0,40% | -18,1604 | 664 | -27,35 |
| 665 | -27,34 | -18192,20 | | 0,14% | 0,05% | -0,04% | -18,18032 | 664 | -27,38 |
| 665 | -27,46 | -18275,50 | | 0,15% | -0,16% | -0,43% | -18,14712 | 664 | -27,33 |
| 666 | -27,36 | -18211,50 | | 0,16% | -0,04% | -0,21% | -18,14712 | 664 | -27,33 |
| 666 | -27,31 | -18181,00 | | 0,16% | 0,11% | 0,04% | -18,1936 | 664 | -27,4 |
| 666 | -27,39 | -18233,10 | | 0,17% | -0,02% | -0,20% | -18,17368 | 664 | -27,37 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 664 | -13,76 | -9130,44 | | 0,16% | -0,24% | -0,49% | | -8,98334 | 662 | -13,57 |
| 664 | -13,80 | -9158,40 | | 0,15% | -0,08% | -0,21% | | -9,09588 | 662 | -13,74 |
| 664 | -13,81 | -9162,99 | | 0,15% | -0,10% | -0,25% | | -9,08926 | 662 | -13,73 |
| 664 | -13,79 | -9148,92 | | 0,15% | -0,09% | -0,22% | | -9,08264 | 662 | -13,72 |
| 664 | -13,84 | -9184,32 | | 0,15% | -0,08% | -0,21% | | -9,12236 | 662 | -13,78 |
| 664 | -13,80 | -9157,14 | | 0,15% | -0,05% | -0,16% | | -9,10912 | 662 | -13,76 |
| 664 | -13,82 | -9167,77 | | 0,15% | -0,08% | -0,22% | | -9,1025 | 662 | -13,75 |
| 664 | -13,86 | -9195,77 | | 0,15% | -0,10% | -0,24% | | -9,12236 | 662 | -13,78 |
| 664 | -13,86 | -9193,95 | | 0,16% | -0,09% | -0,24% | | -9,12236 | 662 | -13,78 |
| 664 | -13,83 | -9178,92 | | 0,16% | -0,03% | -0,12% | | -9,14222 | 662 | -13,81 |
| 664 | -13,85 | -9188,81 | | 0,16% | -0,07% | -0,20% | | -9,12898 | 662 | -13,79 |
| 664 | -13,83 | -9180,00 | | 0,16% | 0,01% | -0,06% | | -9,16208 | 662 | -13,84 |
| 662 | -3,34 | -2207,69 | | 0,09% | -0,21% | -0,37% | | -2,09537 | 661 | -3,17 |
| 662 | -3,34 | -2213,60 | | 0,08% | -0,13% | -0,24% | | -2,14164 | 661 | -3,24 |
| 662 | -3,40 | -2252,47 | | 0,08% | -0,15% | -0,28% | | -2,16808 | 661 | -3,28 |
| 662 | -3,41 | -2258,94 | | 0,17% | -0,15% | -0,29% | | -2,1714 | 660 | -3,29 |
| 662 | -3,42 | -2264,41 | | 0,17% | -0,15% | -0,29% | | -2,178 | 660 | -3,3 |
| 662 | -3,38 | -2237,74 | | 0,17% | -0,06% | -0,13% | | -2,1978 | 660 | -3,33 |

**Conclusion**: **The test has been succeeded.**

- Response time < 20ms
- Converter V/I error < 1%
- SOC from MBMM is linear during charge/discharge at P=constant.
- Converter = Off when receive SOC=0 or under Vcell_min or Vbatt_min
- Major alarm ➔ Battery contactor open (Converter = stopped by Alarm)
- Minor alarm ➔ Battery General Warning (converter = on)
- MBMM = “opening contactor request” ➔ Pconverter = 0 + switch OFF
- The converter respects the MBMM limits
- Battery Efficiency ~ 95,5%
- Current limitation is equivalent to P set-point variation.
- Voltage limitation is managed with loop control:
    - Reduction = 1 * (P / Pn) / s
    - Rising = 0,2*(P / Pn) / s
- MBMM Limitation Delay = MBMM updating + PCS Timing < 400ms + 80ms = 480ms

*All the details are described in the internal confidential document*:
"M208_SCARICA_BATTERIE.doc"

- **Abnormal functioning tests**

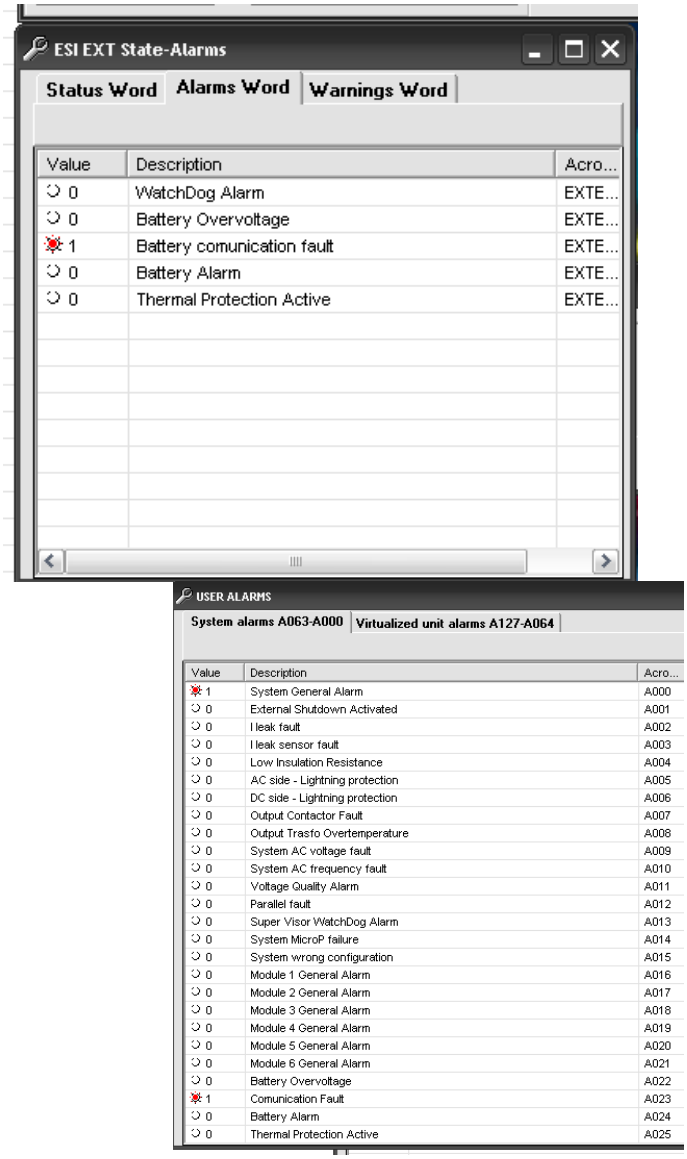
  - **Communication Fault:**

Date of the tests: January 2014.

If during the battery charge or discharge, the communication between:

- **Converter and gateway** is cut off, the module switches off in few seconds.
- **Battery Cabinet and gateway** is cut off, the module switches off in few seconds.
- **Gateway** is switched off**,** the module switches off in few seconds.

In all these cases, the alarm on display is “A23 Battery Communication Fail” (memorised alarm).


ESI EXT State-Alarms
Status Word
Alarms Word
Warnings Word
Value
Description
Acro...
0 WatchDog Alarm EXTE...
0 Battery Overvoltage EXTE...
1 Battery comunication fault EXTE...
0 Battery Alarm EXTE...
0 Thermal Protection Active EXTE...
USER ALARMS
System alarms A063-A000
Virtualized unit alarms A127-A064
Value
Description
Acro...
1 System General Alarm A000
0 External Shutdown Activated A001
0 I leak fault A002
0 I leak sensor fault A003
0 Low Insulation Resistance A004
0 AC side - Lightning protection A005
0 DC side - Lightning protection A006
0 Output Contactor Fault A007
0 Output Trasfo Overtemperature A008
0 System AC voltage fault A009
0 System AC frequency fault A010
0 Voltage Quality Alarm A011
0 Parallel fault A012
0 Super Visor WatchDog Alarm A013
0 System MicroP failure A014
0 System wrong configuration A015
0 Module 1 General Alarm A016
0 Module 2 General Alarm A017
0 Module 3 General Alarm A018
0 Module 4 General Alarm A019
0 Module 5 General Alarm A020
0 Module 6 General Alarm A021
0 Battery Overvoltage A022
1 Comunication Fault A023
0 Battery Alarm A024
0 Thermal Protection Active A025

**Conclusion**: **The test has been succeeded.**

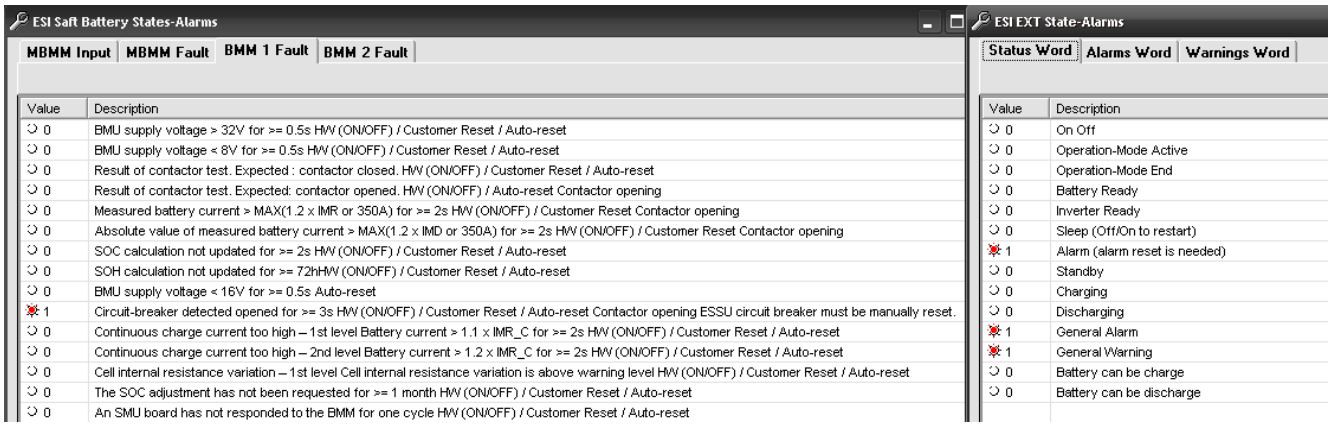
*All the details are described in the internal confidential document*: "M208_ABNORMAL_TEST.doc"

- **Major alarms and minor alarms:**

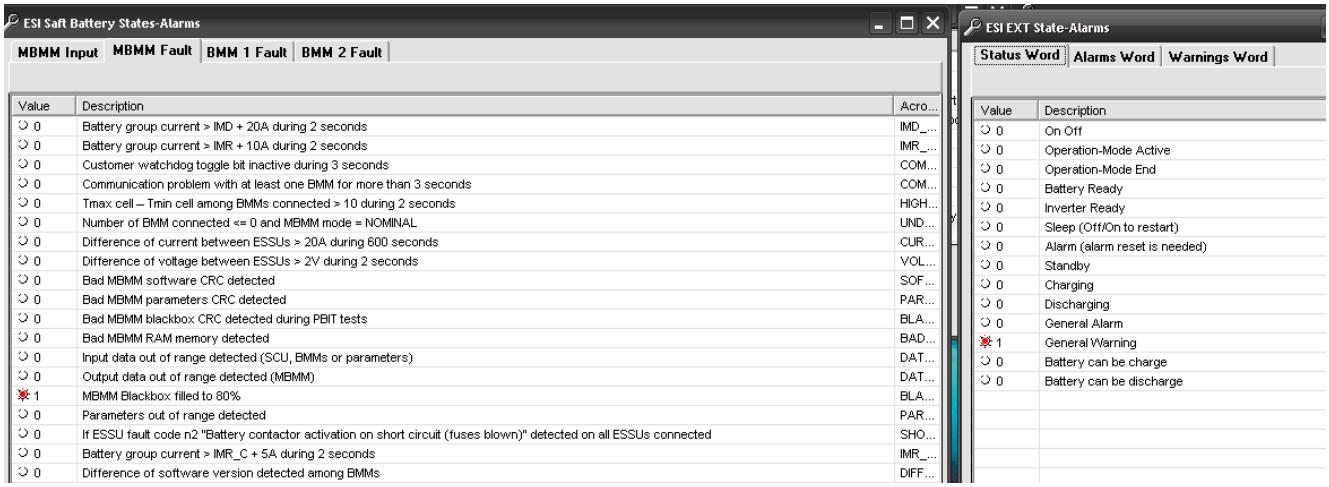
Date of the tests: January 2014.

With the **major alarms,** the battery connections to the converter are not possible (Contactor opening).

At the contrary, with **minor alarms** the connections are still possible.


ESI Saft Battery States-Alarms
MBMM Input
MBMM Fault
BMM 1 Fault
BMM 2 Fault
Value
Description
0 BMU supply voltage > 32V for >= 0.5s HW (ON/OFF) / Customer Reset / Auto-reset
0 BMU supply voltage < 8V for >= 0.5s HW (ON/OFF) / Customer Reset / Auto-reset
0 Result of contactor test. Expected : contactor closed. HW (ON/OFF) / Customer Reset / Auto-reset
0 Result of contactor test. Expected: contactor opened. HW (ON/OFF) / Auto-reset Contactor opening
0 Measured battery current > MAX(1.2 x IMR or 350A) for >= 2s HW (ON/OFF) / Customer Reset Contactor opening
0 Absolute value of measured battery current > MAX(1.2 x IMD or 350A) for >= 2s HW (ON/OFF) / Customer Reset Contactor opening
0 SOC calculation not updated for >= 2s HW (ON/OFF) / Customer Reset / Auto-reset
0 SOH calculation not updated for >= 72hHW (ON/OFF) / Customer Reset / Auto-reset
0 BMU supply voltage < 16V for >= 0.5s Auto-reset
1 Circuit-breaker detected opened for >= 3s HW (ON/OFF) / Customer Reset / Auto-reset Contactor opening ESSU circuit breaker must be manually reset.
0 Continuous charge current too high – 1st level Battery current > 1.1 x IMR_C for >= 2s HW (ON/OFF) / Customer Reset / Auto-reset
0 Continuous charge current too high – 2nd level Battery current > 1.2 x IMR_C for >= 2s HW (ON/OFF) / Customer Reset / Auto-reset
0 Cell internal resistance variation – 1st level Cell internal resistance variation is above warning level HW (ON/OFF) / Customer Reset / Auto-reset
0 The SOC adjustment has not been requested for >= 1 month HW (ON/OFF) / Customer Reset / Auto-reset
0 An SMU board has not responded to the BMM for one cycle HW (ON/OFF) / Customer Reset / Auto-reset
ESI EXT State-Alarms
Status Word
Alarms Word
Warnings Word
Value
Description
0 On Off
0 Operation-Mode Active
0 Operation-Mode End
0 Battery Ready
0 Inverter Ready
0 Sleep (Off/On to restart)
1 Alarm (alarm reset is needed)
0 Standby
0 Charging
0 Discharging
1 General Alarm
1 General Warning
0 Battery can be charge
0 Battery can be discharge

Major alarm → Request for the opening of the battery contactor.


ESI Saft Battery States-Alarms
MBMM Input
MBMM Fault
BMM 1 Fault
BMM 2 Fault
Value
Description
Acro...
0 Battery group current > IMD + 20A during 2 seconds
0 Battery group current > IMR + 10A during 2 seconds
0 Customer watchdog toggle bit inactive during 3 seconds
0 Communication problem with at least one BMM for more than 3 seconds
0 Tmax cell – Tmin cell among BMMs connected > 10 during 2 seconds
0 Number of BMM connected <= 0 and MBMM mode = NOMINAL
0 Difference of current between ESSUs > 20A during 600 seconds
0 Difference of voltage between ESSUs > 2V during 2 seconds
0 Bad MBMM software CRC detected
0 Bad MBMM parameters CRC detected
0 Bad MBMM blackbox CRC detected during PBIT tests
0 Bad MBMM RAM memory detected
0 Input data out of range detected (SCU, BMMs or parameters)
0 Output data out of range detected (MBMM)
1 MBMM Blackbox filled to 80%
0 Parameters out of range detected
0 If ESSU fault code n2 "Battery contactor activation on short circuit (fuses blown)" detected on all ESSUs connected
0 Battery group current > IMR_C + 5A during 2 seconds
0 Difference of software version detected among BMMs
ESI EXT State-Alarms
Status Word
Alarms Word
Warnings Word
Value
Description
0 On Off
0 Operation-Mode Active
0 Operation-Mode End
0 Battery Ready
0 Inverter Ready
0 Sleep (Off/On to restart)
0 Alarm (alarm reset is needed)
0 Standby
0 Charging
0 Discharging
0 General Alarm
1 General Warning
0 Battery can be charge
0 Battery can be discharge

Minor alarm → No opening request.

**Conclusion**: **The test has been succeeded.**

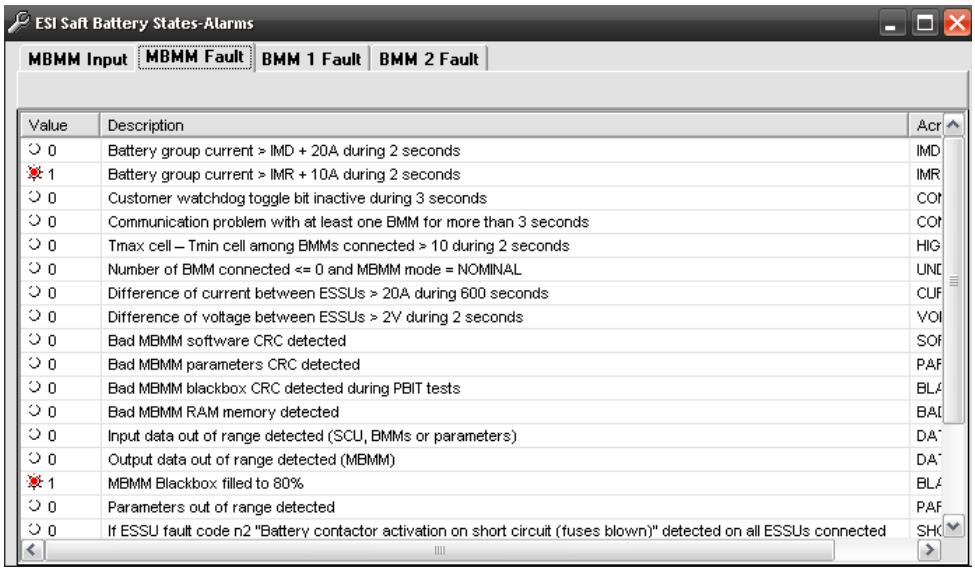
*All the details are described in the internal confidential document*:
"M208_ABNORMAL_TEST.doc"

- **Battery disconnection in case of Overcurrent and Overvoltage:**

Date of the tests: January 2014.

- Overcurrent test:

During the recharge, even if the MBMM requires the ending of the charge because it has sent the command at the converter to reduce at 0A the current (IMR =0), the converter supplies more of 10A and after two seconds the MBMM cuts off the DC voltage; **the overcurrent protection is ok**

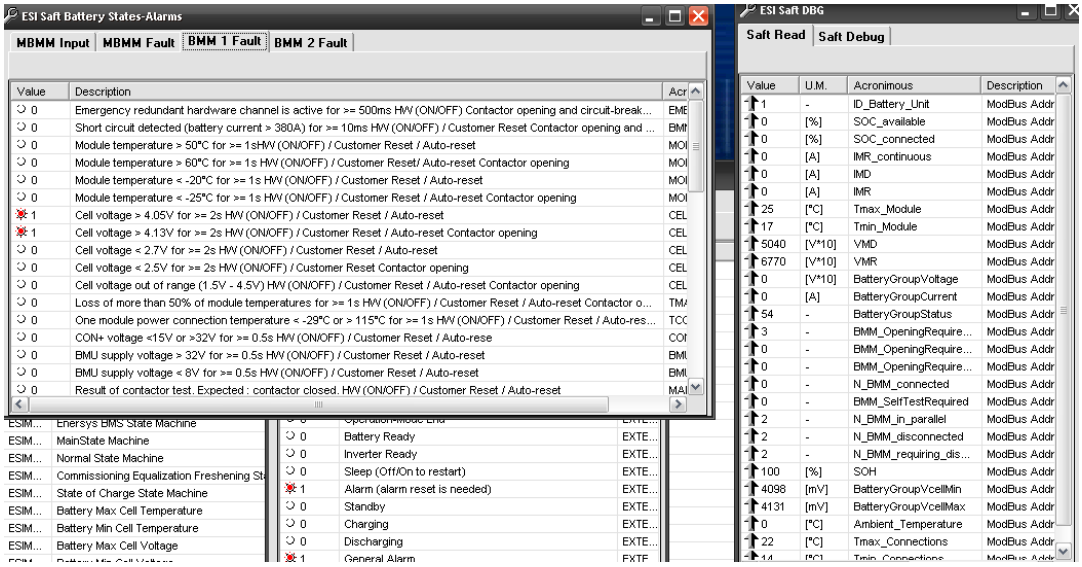

ESI Saft Battery States-Alarms
MBMM Input
MBMM Fault
BMM 1 Fault
BMM 2 Fault
Value
Description
Acr
0 Battery group current > IMD + 20A during 2 seconds IMD
1 Battery group current > IMR + 10A during 2 seconds IMR
0 Customer watchdog toggle bit inactive during 3 seconds
0 Communication problem with at least one BMM for more than 3 seconds
0 Tmax cell – Tmin cell among BMMs connected > 10 during 2 seconds
0 Number of BMM connected <= 0 and MBMM mode = NOMINAL
0 Difference of current between ESSUs > 20A during 600 seconds
0 Difference of voltage between ESSUs > 2V during 2 seconds
0 Bad MBMM software CRC detected
0 Bad MBMM parameters CRC detected
0 Bad MBMM blackbox CRC detected during PBIT tests
0 Bad MBMM RAM memory detected
0 Input data out of range detected (SCU, BMMs or parameters)
0 Output data out of range detected (MBMM)
1 MBMM Blackbox filled to 80%
0 Parameters out of range detected
0 If ESSU fault code n2 "Battery contactor activation on short circuit (fuses blown)" detected on all ESSUs connected

- Overvoltage test:

The test is to check the trip threshold if the voltage of the cells is more than 4,13V.

In this case the MBMM sends a command to the internal contactor to open the connection between battery cabinet and converter.

In this case the modules of "converter system" switch off. The abnormal test is done supplying current, even if the MBMM sends a command to reduce the current to 0 (IMR=0). In this way the voltage battery increase the charge until it reaches 4,13V by cell.


ESI Saft Battery States-Alarms
MBMM Input
MBMM Fault
BMM 1 Fault
BMM 2 Fault
Value
Description
Emergency redundant hardware channel is active for >= 500ms H/W (ON/OFF) Contactor opening and circuit-break...
Short circuit detected (battery current > 380A) for >= 10ms H/W (ON/OFF) / Customer Reset Contactor opening and ...
Module temperature > 50°C for >= 1sH/W (ON/OFF) / Customer Reset / Auto-reset
Module temperature > 60°C for >= 1s H/W (ON/OFF) / Customer Reset/ Auto-reset Contactor opening
Module temperature < -20°C for >= 1s H/W (ON/OFF) / Customer Reset / Auto-reset
Module temperature < -25°C for >= 1s H/W (ON/OFF) / Customer Reset / Auto-reset Contactor opening
Cell voltage > 4.05V for >= 2s H/W (ON/OFF) / Customer Reset / Auto-reset
Cell voltage > 4.13V for >= 2s H/W (ON/OFF) / Customer Reset / Auto-reset Contactor opening
Cell voltage < 2.7V for >= 2s H/W (ON/OFF) / Customer Reset / Auto-reset
Cell voltage < 2.5V for >= 2s H/W (ON/OFF) / Customer Reset Contactor opening
Cell voltage out of range (1.5V - 4.5V) H/W (ON/OFF) / Customer Reset / Auto-reset Contactor opening
Loss of more than 50% of module temperatures for >= 1s H/W (ON/OFF) / Customer Reset / Auto-reset Contactor o...
One module power connection temperature < -29°C or > 115°C for >= 1s H/W (ON/OFF) / Customer Reset / Auto-res...
CON+ voltage <15V or >32V for >= 0.5s H/W (ON/OFF) / Customer Reset / Auto-rese
BMU supply voltage > 32V for >= 0.5s H/W (ON/OFF) / Customer Reset / Auto-reset
BMU supply voltage < 8V for >= 0.5s H/W (ON/OFF) / Customer Reset / Auto-reset
Result of contactor test. Expected : contactor closed. H/W (ON/OFF) / Customer Reset / Auto-reset
Enersys BMS State Machine
MainState Machine
Normal State Machine
Commissioning Equalization Freshening St
State of Charge State Machine
Battery Max Cell Temperature
Battery Min Cell Temperature
Battery Max Cell Voltage
Battery Ready
Inverter Ready
Sleep (Off/On to restart)
Alarm (alarm reset is needed)
Standby
Charging
Discharging
General Alarm
ESI Saft DBG
Saft Read
Saft Debug
Value
U.M.
Acronimous
Description
ID_Battery_Unit
SOC_available
SOC_connected
IMR_continuous
IMD
IMR
Tmax_Module
Tmin_Module
VMD
VMR
BatteryGroupVoltage
BatteryGroupCurrent
BatteryGroupStatus
BMM_OpeningRequire...
BMM_OpeningRequire...
BMM_OpeningRequire...
N_BMM_connected
BMM_SelfTestRequired
N_BMM_in_parallel
N_BMM_disconnected
N_BMM_requiring_dis...
SOH
BatteryGroupVcellMin
BatteryGroupVcellMax
Ambient_Temperature
Tmax_Connections
ModBus Addr

**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*: "M208_ABNORMAL_TEST.doc"

- **Over-discharge condition:**

Date of the tests: January 2014.

The test is made by disabling:

- the “Vcell min Battery Group = < 2,7V”,
- “SOC_connected=0%” controls,
- “V Battery Group Min”,
- "Opening Request" from BMM
- Current Limit Used: IMD + 5A.

The first part of discharge is at nominal power. Near the end of discharge the power is reduced to avoid any damage of the battery for over discharge.

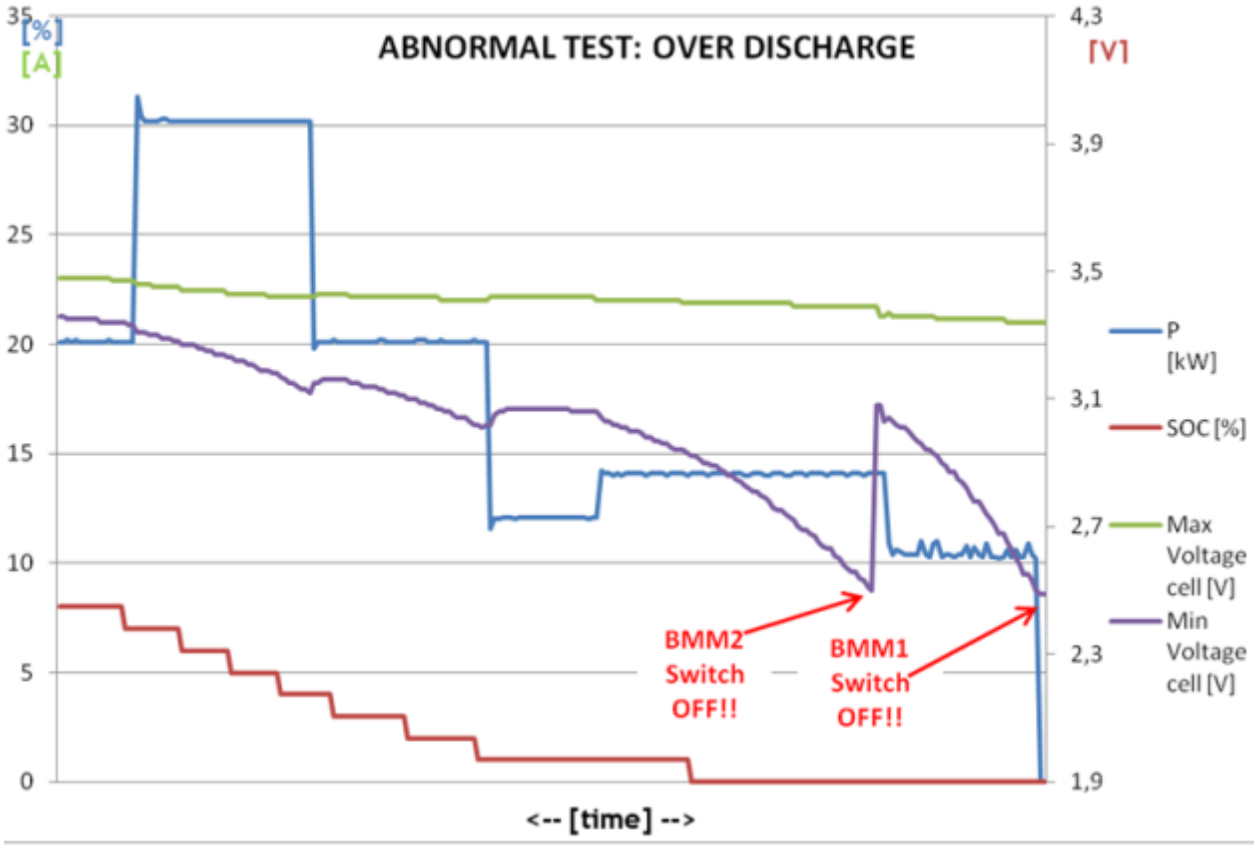
The over-discharge test is a strong stress for the battery. The cell voltage arrives below 2,5V.

During the test, the first battery cabinet (BMM 2) with cell voltage <2,5V switches off and the discharge continues with the other battery cabinet (BMM 1).

When one cabinet is disconnected, automatically the MBMM sends a command to the converter to limit the max discharge current (IMD). By program, the value setting is = IMD+5A.

When also the “cell voltage” of second battery cabinet reaches 2,5V, the discharge finishes.

For over-discharge reasons, now the system remains in stand-by condition unless the cell voltage will be > 2,7V. This slow charge is made by two BMM.




**Conclusion**: **The test has been succeeded.**

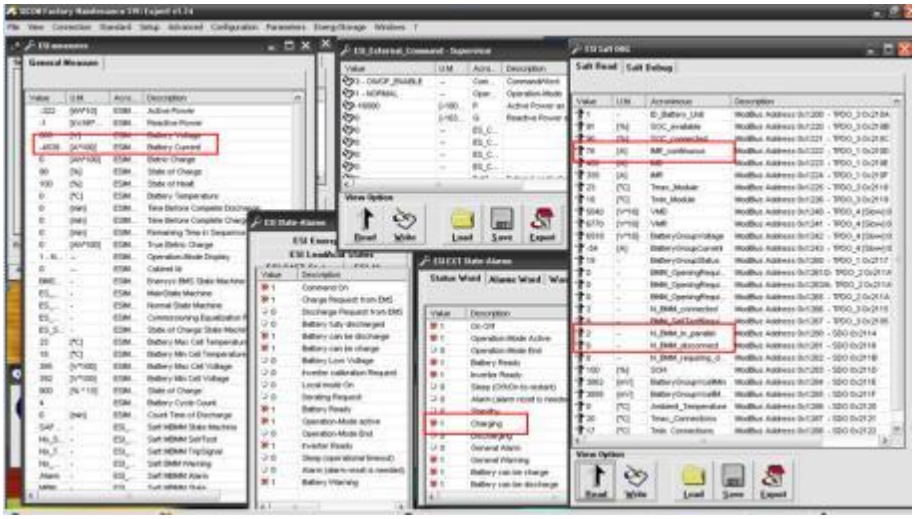
*All the details are described in the internal confidential document*: "M208_ABNORMAL_TEST.doc"

- **Disconnection battery cabinet during charge & discharge:**

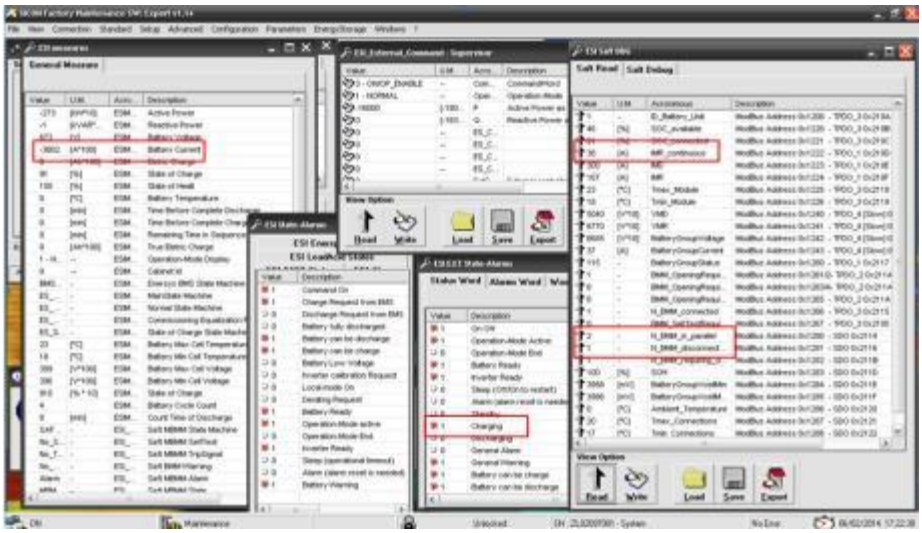
Date of the tests: January 2014.

- Disconnection during battery charging:

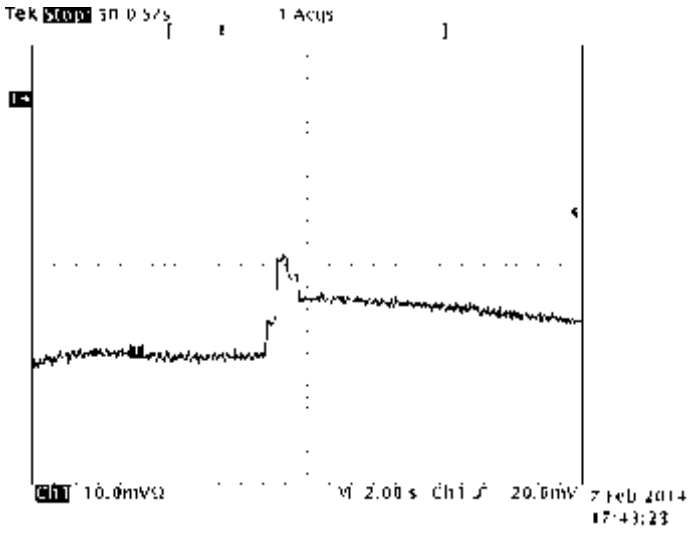
As showed below there are two batteries cabinet connected in parallel in charging condition: the IMR_continous setting is 76A and the charging current is 45A



Now one battery cabinet is cut off and the new IMR_continous setting is 38A and the charging current is 38A.



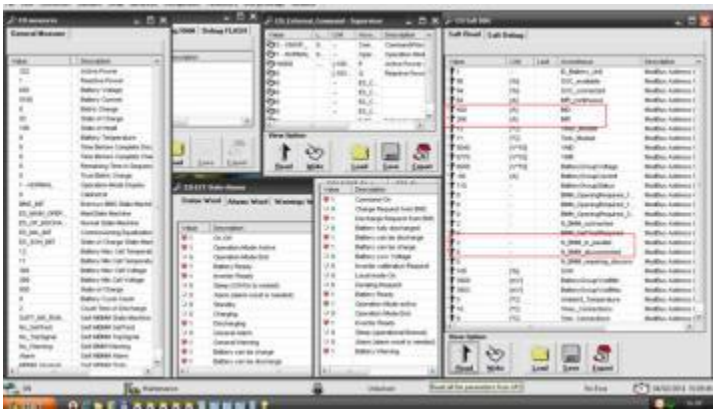
Any current overshoot during cut off of one battery cabinet



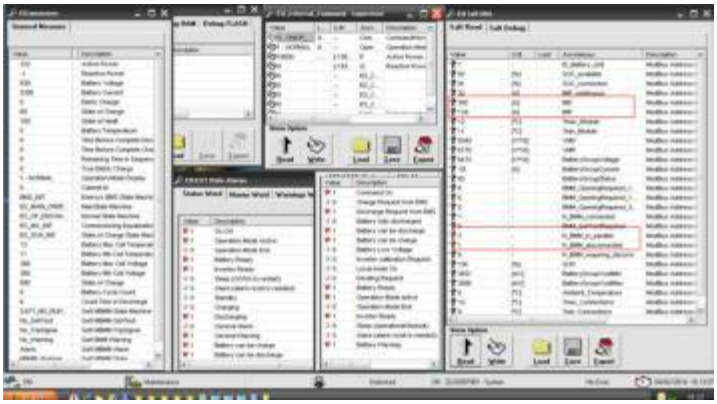

With two batteries cabinets the charge current is 45A, after cut off of one battery cabinet the current is reduced to 38A.

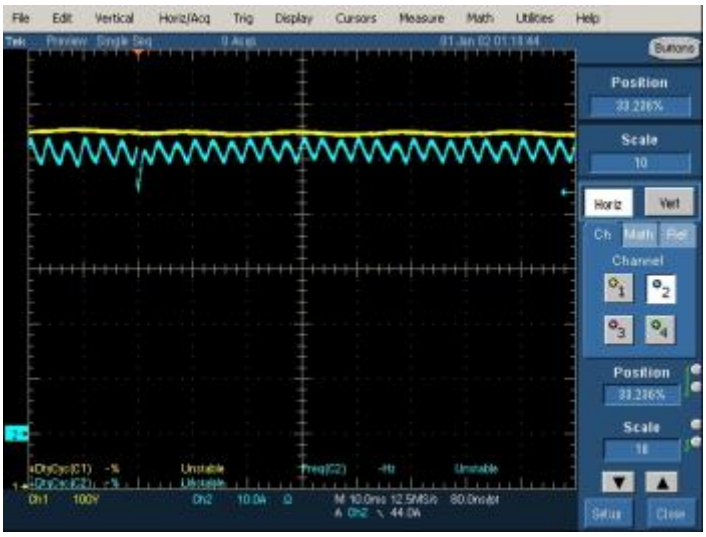
- Disconnection during battery discharging:

As showed below, there are two batteries cabinet connected in parallel in discharging condition: the IMD setting is 400A:



Now, one battery cabinet is cut off and the new IMD setting is 300A:






**CH1=100V/div DC Voltage** **CH2= 10A/div DC Current**

No current overshoot can be observed during the cutting off of one battery cabinet.

**Conclusion**: **The test has been succeeded.**

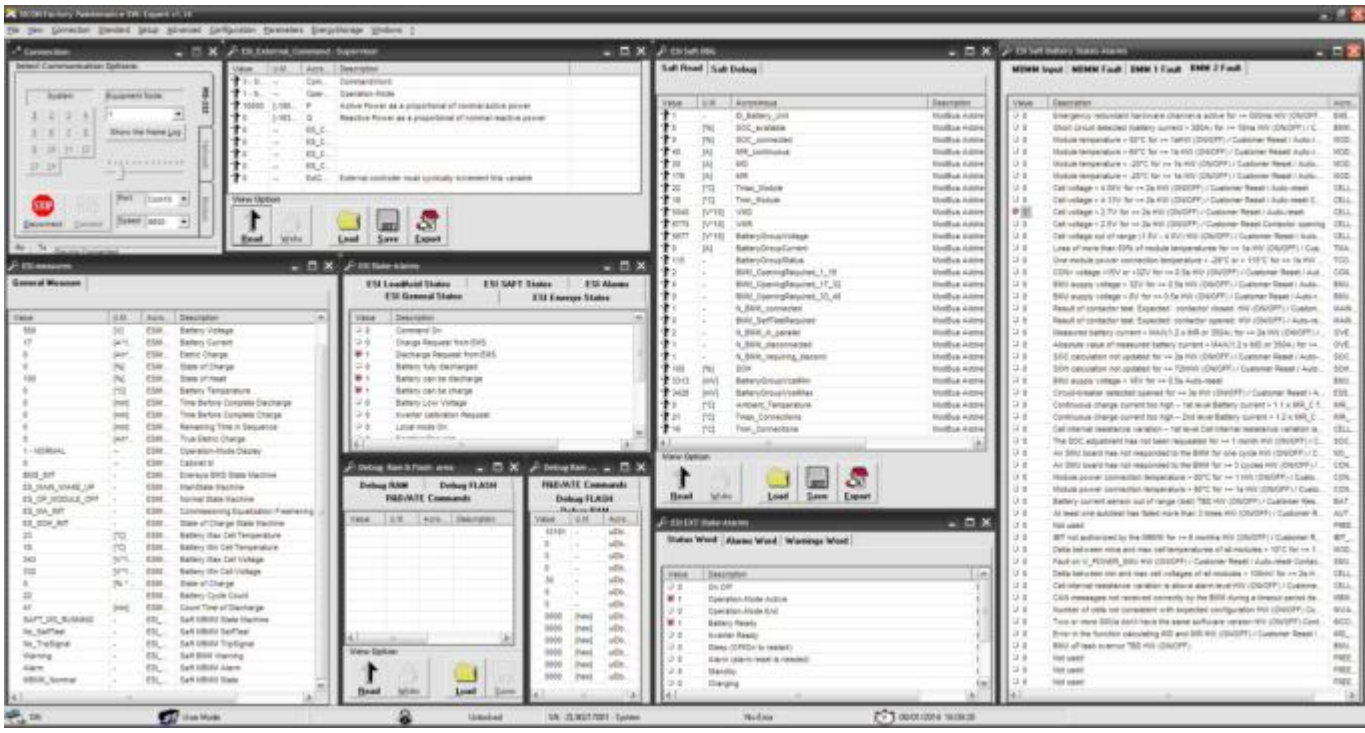
*All the details are described in the internal confidential document*: "M208_ABNORMAL_TEST.doc"

- **Converter disconnection in case of opening request coming from MBMM :**

Date of the tests: January 2014.

The test is made by disabling the security parameter (SOC=0%) so the voltage can reach the value allowing the MBMM command.

During the discharge test, when one cell voltage of battery cabinet is lower than 2,7V, the BMM sends a command to MBMM and immediately it sends to the converter the “opening contactor request”. The converter reduces to 0 the power and sends the command to open the contactors. At this moment all the cabinet contactors are opened.



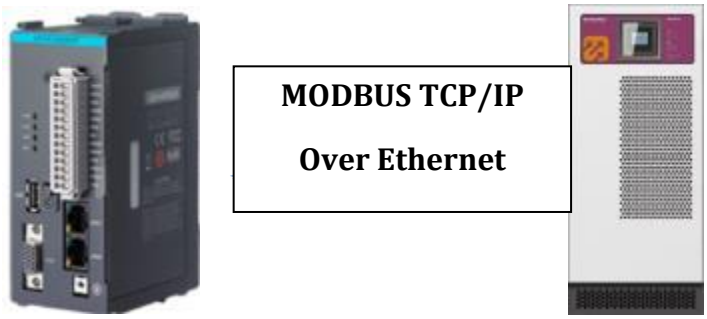
**Conclusion**: **The test has been succeeded.**

*All the details are described in the internal confidential document*: "M208_SCARICA_BATTERIE.doc"

- **Communication between SUNSYS PCS² 33 & ALSTOM FCU**

Date of the tests: March 2014.

The objective of this test is to verify the **completeness of exchanged data between the ALSTOM FCU & the SOCOMEC SUNSYS PCS²**.




The tests have been based on the following specification built in collaboration with ALSTOM: "NG_MCU&FCUs_Socomec_Modbus_Specification V1.2"

| ITEMS UNDER TEST | RESULT |
|---|---|
| **General protocol Modbus TCP** | |
| General verifications | Ok |
| **Command Word 0x1100** | |
| Switch On-Off | Ok |
| Operation-Mode Enable On | TBC: Off state |
| Alarm Reset (simulated some different alarm conditions) | Ok |
| **Operation-Mode 0x1101** | |
| Standby | Ok |
| Normal Mode | Ok |
| **P Setpoint 0x1102** | |
| Active Power | Ok |
| **Q Setpoint 0x1103** | |
| Reactive Power | TBC. |

| | |
|---|---|
| **Watchdog Management 0x1108** | |
| verified the correct functionality removing cable or<br><br>blocking protocol | Ok |
| free-running counter is updated by master every 1 sec | Ok |
| **Status Word 0x1150** | |
| Test of all bits | Ok |
| **Alarm Word 0x1151** | |
| Test of all bits | Ok |
| **Warning Word 0x1152 : all bits are correct** | |
| Test of all bits | Ok |
| Verified in particular status of Bit12 “Local Mode Enabled” | Ok |
| **All measures of “*Supervisor Variables*” Area.** | |
| Cos PHI | TBC: Problem in value visualization |
| Time variables (0x1162 and 0x1163) | Don't care (not needed) |
| All other variables in the table | Ok |
| **“*Battery Parameters*” Area** | |
| Test of all parameters | Ok |
| **“*Monitoring*” System Area** | |
| System States | Ok |
| System Warnings | Ok |
| System Alarms | Ok |
| ***"Monitoring"* Unit Area** | |
| System/Unit Measurements | Not verified. To be checked if needed. |
| System/Unit Statistics | Not verified. To be checked if needed. |
| System Settings | Not verified. To be checked if needed. |
| Date & Time | Not verified. To be checked if needed. |
| Battery Specific Area | Not verified. To be checked if needed. |

**Conclusion**: **The test was quite positive but there are some pending points that we will solve during the final tests of the full equipment (W38).**

- **Next Steps:**

In order to complete or to confirm the previous described tests, a full week of tests is planned in W38 of 2014 with all the contributors (SAFT / ALSTOM / SOCOMEC) on the first container. It will be also the first opportunity to tests also all the auxiliaries (HVAC & FSS enslavement).

Then, during October & November, the first container will be fully tested on the "Concept Grid" (Les Renardières – EDF R&D laboratory site) with the consideration of real grid disturbance.

These tests will be supported by the document "M190V_NiceGrid_OnGrid_rev04.docx" which is still under construction.

## *3.2.4 References*

| REF | Topics | Files names |
|---|---|---|
| **[REF01]** | Communication & state machine specifications between SUNYS PCS² & SAFT battery. | SOCOMEC_PCS_Islanding_Modbus_Protocol_REV_07 |
| **[REF02]** | Specific communication specification for SAFT battery. | SOCOMEC_EnergyStorage_Modbus_Protocol_SAFT_REV_03 |
| **[REF03]** | Specification of the energy storage management of SAFT battery. | SOCOMEC_PCS_Saft_Battery_REV_01 |
| **[REF04]** | Communication specification between SUNYS PCS² & ALSTOM FCU. | NG MCU & FCUs SOCOMEC Modbus Specification V1.2 |
| **[REF05]** | Main tests plan. | M190V_NiceGrid_OnGrid_rev04 |

# 3.3 Results of electrical tests on individual batteries

## 3.3.1 Context

This chapter presents the results of the tests conducted on residential energy storage systems, which are owned by the project partners and will be installed at individual customers' premises as part of the NICE GRID project. In order to handle the massive insertion of distributed photovoltaic energy resources in a specific area, the aim of the NICE GRID project is to exploit flexibilities (such as energy storage) to manage supply – demand balance. In addition to these residential storage systems, the NICE GRID project will mainly test on grid storage, demand response and islanding of a low-voltage distribution grid.

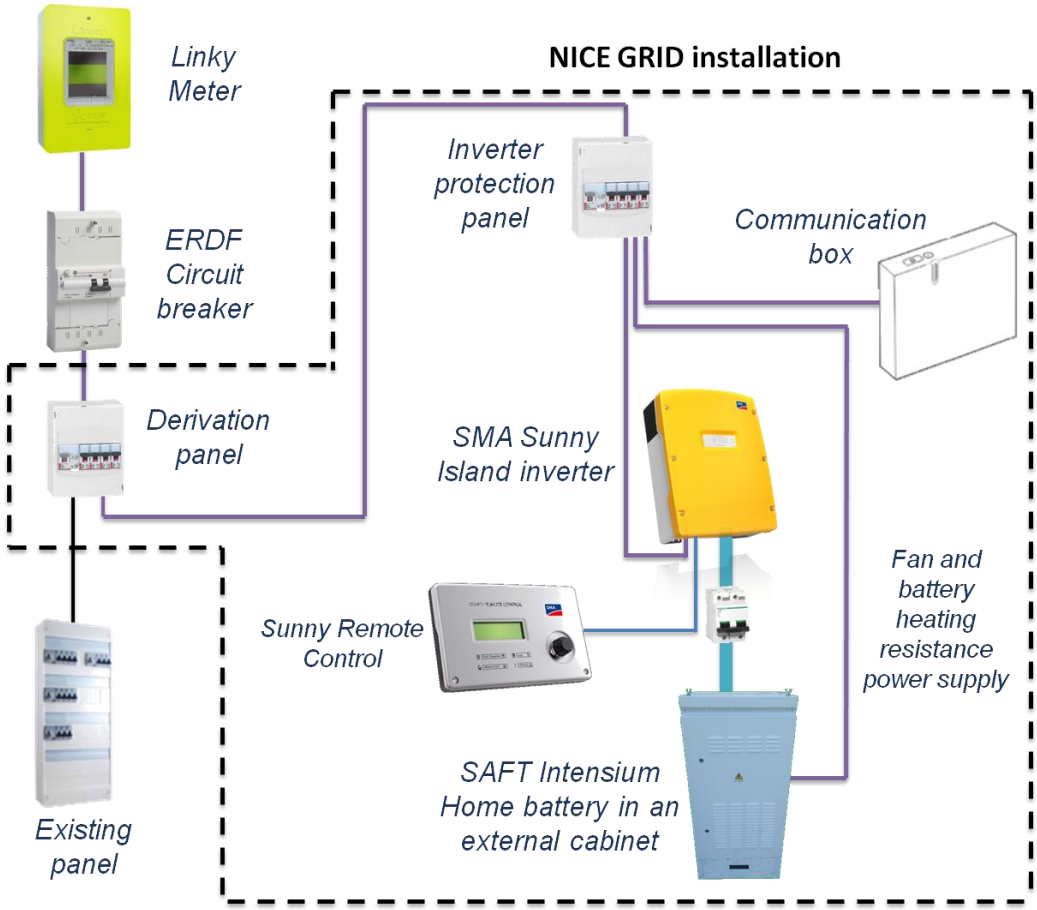



*Figure 61: Residential energy storage system diagram*

The systems considered in this case, presented on Figure 61, consist of a 4 kWh Li-Ion battery produced by SAFT and a 4.6 kVA inverter manufactured by SMA. These systems are controlled both locally (with higher priority) and by a centralized management system, which manage their aggregation. They will be connected downstream of the customers' supply location (i.e. in their premises) by a 3rd party installer assigned by the project.

The objectives of the tests presented here are to check:

- The correct integration of components from different manufacturing suppliers and the proper functioning of the full system (especially regarding its security)
- The compliance with the existing standards and regulations for the electrical connection (the French standard called NF C 15-100, …)
- The appropriateness of important parameters (for example response time) in regards with the project needs

The results of the functional and components unitary tests (for example inverter electromagnetic compatibility) are not given here and the management tests are presented in the part *Assessment of PV installation*). The tests have been conducted by EDF R&D on ConceptGrid, a new connected test facility (where a full installation has been completed: protection system, inverter and battery but without the communication box). Furthermore, design and calculation of power connection have been validated by an independent control office (SOCOTEC).

## 3.3.2 Results

Tests / studies results are focused on the following points:

- System documentation
- Regulatory compliance and electrical connection diagram
- Specific tests and studies for the security of the full system
- Important operational characteristics
- Incidents recorded during the tests

### System documentation

#### *Summary table*

| Tests / Studies | Results | Comments |
|---|---|---|
| **System representativeness** | OK | - |
| **General information** | OK | - |
| **CE marking** | OK | - |
| **Declaration of compliance of the decoupling protection** | OK | Compliant to VDE 0126-1-1 VFR 2013 with some configuration |
| **Installation instructions and wiring diagram** | OK | Procedure and training for the full system installation |
| **Declaration of connection to the Distribution System Operator** | OK | - |
| **Battery safety data sheet** | OK | - |
| **Functional description** | Non-applicable | - |
| **Emissions description** | OK | - |
| **Layout diagram and installation recommendations** | OK | Risk analysis at the project level for the full system |
| **Restriction of use** | OK | Risk analysis at the project level for the full system |

| | | |
|---|---|---|
| **Action to be taken against any failure in the system** | OK | Risk analysis at the project level for the full system |
| **Transport constraints** | OK | - |
| **Constraints and information for customer's insurance company** | OK | Template of a letter that can be sent by the customer to his insurance company |

- ***System representativeness***

The tested system is composed of the SAFT battery and the SMA inverter. The communication gateway and the local management system were not available during the test, but their performances have been measured and are reported in the part *Assessment of PV installation*.
However, the system can be controlled for the tests via a PC using a communication link and protocols (data, variables...) identical to the ones that will be implemented on the field. Furthermore, no safety feature is carried out by the communication gateway or the local control system; they can be replaced by a simple PC or by the SMA inverter control software (Sunny Data Control) for the tests. The communication channel used to control the inverter is the RS485 channel and all the safety features are present and operational. The battery tested here is the indoor battery, very similar to the outdoor version that will be used in NICE GRID. The indoor and outdoor versions, presented on Figure 62, have no functional differences. The two versions are installed in ConceptGrid and their installation has been also validated by an independent control office (SOCOTEC).

*Figure 62: Indoor and outdoor versions of the battery*

- ***General information***

Information about each component (battery and inverter) is given in manufacturers' documentation. Some data are presented here on an indicative basis:

- Inverter nominal power: 4600 VA
- Battery capacity: 4 kWh
- Battery voltage (MIN – MAX): 42 V – 56 V
- Constraints on battery use depending on the state of charge and temperature
- Battery storage constraints

- ***CE marking***

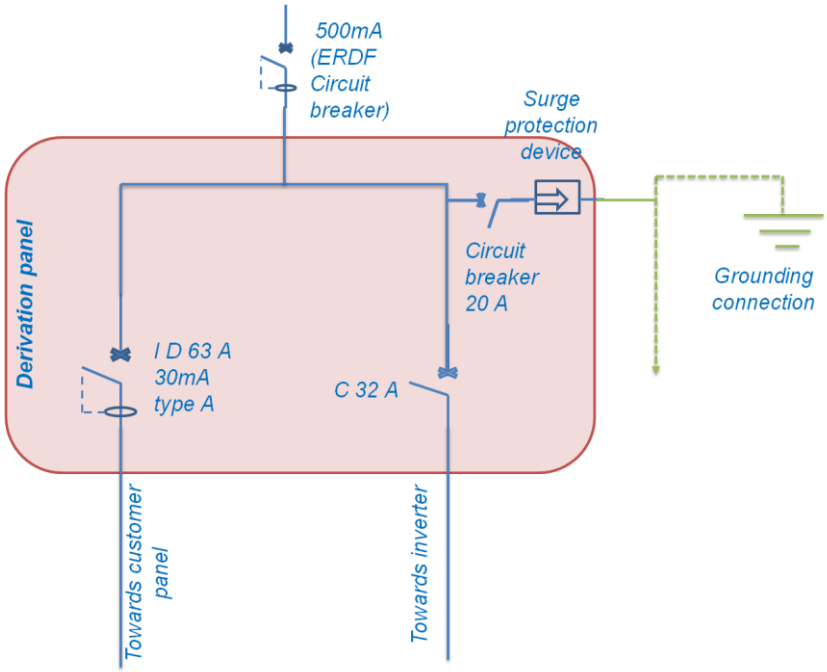
Both the battery and inverter have CE marking (confer external document: "*MPS-ZE-HK-VDE01261A1VFR13-fr-15 déclaration SMA conformité DIN.pdf*").

- ***Decoupling protection***

The inverter must be equipped with a decoupling protection in conformity with the Distribution System Operator (DSO) reference sources. Yet, by default this inverter is in conformity with VDE ARN 4105, but its parameters are configurable, so with some configuration, it can be in conformity with the mandatory standard for a power connection in France (VDE 0126-1-1 VFR 2013).
The decoupling thresholds for the standard VDE 0126-1-1 VFR 2013 are:

- 0.8 $V_n$ (184 V) < V < 1.15 $V_n$ (264,5 V)
- 47,5 Hz < f < 50,4 Hz

- ***Detailed installation instructions and wiring diagram***



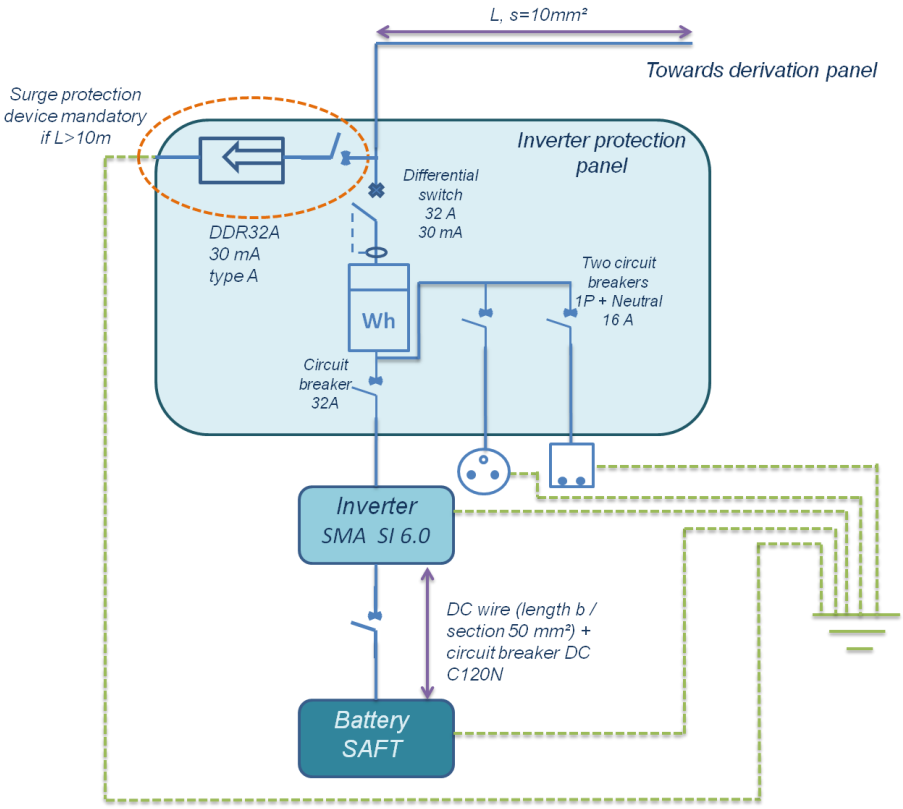

L, s=10mm²
Towards derivation panel
Surge protection device mandatory if L>10m
Inverter protection panel
Differential switch 32 A 30 mA
DDR32A 30 mA type A
Two circuit breakers 1P + Neutral 16 A
Wh
Circuit breaker 32A
Inverter SMA SI 6.0
DC wire (length b / section 50 mm²) + circuit breaker DC C120N
Battery SAFT

*Figure 63: Single line electrical diagram*

A single line electrical diagram has been designed and validated by an electrical control office. It consists of a derivation panel downstream of the tie breaker (general equipment for control and protection), as well as a panel located next to the storage system.
No battery pole is connected to the ground; the earthling connection scheme on the AC side is a VT (voltage transformer).
Installation instructions for each component are described in manufacturers' documentation. A training session for the installer is planned in September 2014 to present the procedures and the installation of the full system.

- ***Information to the Distribution System Operator for the connection***

All the needed information is available: single line diagram, inverter power...
The connection principle is similar to the one for a classical load.

- ***Safety data sheet***

The battery safety data sheet is provided by the supplier (confer external document: "*13-2400-mu outdoor intensium home -v2 - fr.pdf*").

- ***Functional description***

The functional description is not mandatory for the tests.

- ***Emissions description***

The main component most likely to release emissions is the Li-Ion battery. In normal operation, no

emission is released. On accidental operations (fire), released emissions are described in the battery safety data sheet. It consists mainly of carbon monoxide CO and others combustion products in very small quantities. The installation recommendations take into account these emissions, this is why outdoor version of the battery has been chosen by the project and will be installed in the customer's premises.

- ***Layout diagram***

Layout guidelines are given for each component (for example the battery must not be installed in a living room). At the project level, a risk analysis has been achieved, containing layout recommendation for the full system.

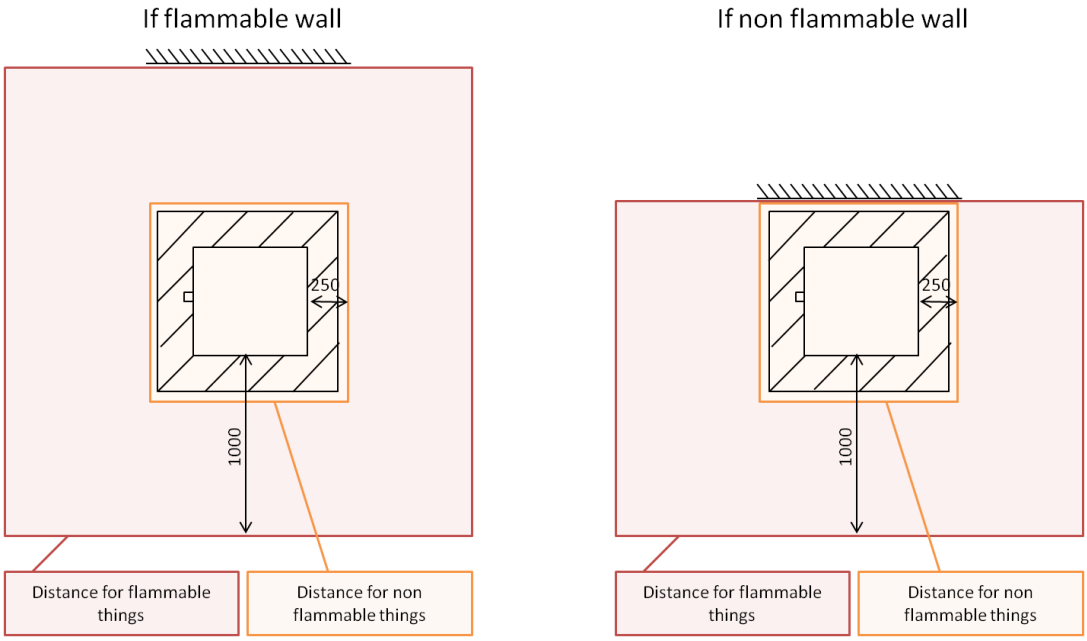



*Figure 64: Safety distance around the battery (in mm)*

- ***Restriction of use***

Restrictions of use are given for each component (for example an indoor battery must not be used outdoor). At the project level, a risk analysis has been achieved, containing restrictions of use for the full system.

- ***Action to be taken against any failure in the system***

Actions to be taken in case of a failure (and the identification of each failure) are given for each component. A prevention data sheet has been written and will be given to the residential customers so they know how to react in case of a system failure. Furthermore at the project level, a risk analysis has been achieved, synthesizing all the actions for the full system.

- ***Transport constraints***

The strongest constraints concern the battery. These constraints are clearly identified in the manufacturer's data sheet. The 3rd party installer will be provided with a training session informing him of the risks and procedures when dealing with the transport of Li-Ion battery.

- ***Information for the insurance company***

A template of a letter that has to be sent by the customer to his insurance company has been prepared, explaining particularly the presence of the battery in the energy storage system provided to the customer.

## Regulatory compliance and electrical connection diagram

- ***Summary table***

| Tests / Studies | Results | Comments |
|---|---|---|
| **Compliance with standard NF C15-100** | OK with reservations | Additional labels |
| **Protections and conduits dimensions** | OK | - |

- ***Compliance with standard NF C15-100***

Even if the electrical installation standards do not deal with installation of storage systems via battery connected to the grid, the NICE GRID systems compliance is estimated relative to NF C15-100 standard and based on UTE C15-712-1 and C15-712-2 standard guides.
The installation principles considered in our project (reference to the document presenting the installation recommendations) state that:

- The customer's existing installation will not be deeply modified, indeed the system will be added as an additional derivation downstream of the tie breaker
- Since it is not possible to check the customer's existing installation, it must be protected by adding a 30mA differential switch
- Overvoltage protection is ensured on the AC side (alternatively – at the inverter output) by a circuit breaker installed in the derivation panel (downstream the tie breaker) and by another circuit breaker installed in the panel close to the inverter in accordance with C15-712-1 guide (scheme for the surpluses injection installations)
- The overcurrent protection on the DC side is ensured by a fuse in the battery in accordance with the high short-circuit power. Similarly, the protection on the AC side of the inverter ensures a protection on the DC side. Finally, it is important to note that the conduit between the battery and the inverter has a maximum length of 2m. If this conduit is longer than 2m, then an additional circuit breaker will be added
- Protection against direct contacts is ensured on the AC side by the use of adapted conduits, mechanically protected. On the DC side, the protection is ensured mechanically (conduits between the battery and the inverter must be protected) and by the fact that the DC bus voltage is less than 60V in all cases
- Protection against indirect contacts is ensured on the AC side from the inverter to the grid by a differential protection. From the grid to the inverter, the protection is ensured by the use of class 2 conduits mechanically protected. On the DC side, protection against indirect contacts is ensured by a voltage never exceeding 120V and by an internal isolation transformer in the inverter
- The battery is equipped with a visible and accessible disconnect switch
- The battery is locked in a cabinet
- Since the battery does not release hydrogen or any other type of gas in normal condition,

only the manufacturer's recommendations regarding free space and ventilation must be respected

- Additional labels will be put on each component in concordance with the electrical diagram, to be able to identify them easily and for safety reasons (confer Figure 65)

Production autonome
Coupure utilisation a.c.
RISQUE DE PRÉSENCE DE PLUSIEURS SOURCES DE TENSION
ISOLER LES SOURCES AVANT TOUTE INTERVENTION

*Figure 65: Example of additional labels*

- ***Protections and conduits dimensions***
  - The resistance value of the customer's local grounding connection must be measured, and equal to no more than 100 ohms (NF C15-100)
  - The tie breaker calibre must be adapted to the storage system (nominal power 4.6 kW)
  - The differential switch between the tie breaker and the customer's panel must have a current rating adapted to the tie breaker calibre (63 A for AGCP 30-60 and 100 A beyond)
  - This differential switch has been chosen with respect to type A, because of the inverter in the installation
  - A surge protection device is installed in the inverter – storage system line in accordance with UTE C15-712 guide recommendations
  - A 32 A circuit breaker protects the inverter line (manufacturer recommendation)
  - A 30 mA, 32 A, type A differential circuit breaker is installed at the inverter AC output (manufacturer recommendation)
  - A surge protection device is mandatory if the conduit between the inverter and the installation remaining equipments is longer than 10 m in accordance with UTE C15-712-1 guide
  - The battery protection fuse calibre is 200 A
  - The grounding connector cross section for the inverter must be at least 16 $mm^2$ copper (manufacturer recommendation)
  - The alternative conductors cross section for the inverter must be at least 10 $mm^2$ copper (manufacturer recommendation)
  - The battery is delivered with two 50 $mm^2$ aluminium wires with a length of 2 m. If necessary, these wires could be extended but an additional DC circuit breaker must be added.

- **Specific tests and studies for the security of the full system**
  - ***Summary table***

| Test / Studies | Results | Comments |
|---|---|---|
| **Risk analysis** | OK | Risk analysis at the project level for the full system |
| **Safety features identified** | OK | - |
| **Decoupling protection** | OK | Compliant with some configuration |
| **Reconnection to the network** | OK | - |
| **AC and DC startup currents** | OK with reservations | Procedure to follow for a noticeable disconnection operation |
| **Over-circuit and short-circuit behaviour** | OK | - |
| **Differential protections** | OK | - |
| **Grounding connection diagram** | OK | - |
| **Transient on the DC bus** | OK | - |
| **Safety chain** | OK | - |
| **Internal communication** | OK | - |
| **Battery management** | OK | No self tests management but maintenance visit every 6 months |

  - ***Risk analysis***

A risk analysis for the battery has been achieved by the manufacturer. It gives installation and operation conditions for the battery.
At the project level, a risk analysis for the full system has also been achieved. This risk analysis will be checked by an independent control office before the installation in the customer's premises.

  - ***Safety features identified***

Safety features of the battery are clearly identified and are sufficient to ensure its safe operation independently of the rest of the system. It mainly concerns the supervision of each part of the battery (voltage), some specific temperature values and the total current by the Battery Management Module (BMM).
These supervision functions are software but hardware safeties are also present for redundancy.
In case of anomaly detection, an alarm is generated on the communication bus and when appropriate (depending on the gravity of the anomaly), the main switch is open. The battery is then completely isolated from the rest of the system.
The correct operation of this electrical switch is automatically tested every 6 months.
In case of severe anomaly on one of the cells, which may appears in spite of the safety features of the BMM; they are equipped with a CID (Current Interruption Device). The CID is a valve which opens in case of overpressure inside the cell and mechanically interrupts the flow of electrical current. The internal features rely on opening the circuit, indeed the battery manufacturer assures

us that when there is no current, there is no risk of fire in the battery.

- ***Decoupling protection***

After some modification in the configuration parameters, the decoupling protection is compliant with the standard VDE 0126-1-1 VFR 2013, which decoupling thresholds are:

- 0.8 $V_n$ (184 V) < V < 1.15 $V_n$ (264,5 V)
- 47,5 Hz < f < 50,4 Hz for VFR 2013

- ***Reconnection to the network***

The reconnection time to the network after a power cut due to the decoupling protection is 5 s, in accordance with VDE 0126-1-1.

- ***AC and DC startup currents***

The startup current on the AC side (at the input breaker closing) of the inverter is very low (below 1 A peak). This does not require any specific adaptation for the protections.
On the DC side, the pre-charging sequence of the battery must be respected, which means:

- The DC disconnect switch of the battery (customer noticeable disconnection) must be closed
- The starting sequence of the battery can then be carried out (ON/OFF button on the BMM)

This allows pre-charging the inverter while limiting the inrush current due to the capacitors.
Once the system is running, the disconnect switch can be maneuvered in a short period of time (the capacitors remain loaded), but if this protection is open for too long (30 s), the starting sequence must be carried out once again.
This procedure to be followed is described in the safety instructions installed close to the system, but anyway if the battery is off for some reason, installer will have to come to check and restart the system.

- ***Over-circuit and short-circuit behavior***

On the AC side, the system is protected by the network connection (“infinite” short-circuit power) and over-current protections. The inverter short-circuit power is 12 kW, which is suitable with the chosen protections.
On the DC side, the system is protected downstream by the battery fuse and upstream by a C32 circuit breaker.

- ***Differential protections***

The differential protections used are those recommended by the inverter manufacturer SMA. Tests showed the proper functioning of these protections (resistive grounding leakage 30 mA).

- ***Grounding connection diagram***

On the AC side of the inverter, the grounded connection is Voltage Transformer. On the DC side, no battery pole is grounded (floating DC voltage).

- ***Transient on the DC bus***

Tests for operating the DC disconnect switch to charge and discharge have not showed evidence of important over-voltage on the DC bus (< 60 V).

- ***Safety chain***

Wherever possible, some safety chains of the battery were tested (example: hardware redundancy, too important current…). All tests showed a proper operation.

- ***Internal communication***

The system has two communication links:

- Between the inverter and the outside, link to set the operating point and send alarms for example
- Between the battery and the inverter, this link allows the battery to send over time its voltage and current limits. Although this link is not a safety feature (as the loss of such a link does not stop the monitoring of the battery by the BMM), it allows the inverter to meet the charging and discharging constraints.

The loss of the communication link between the battery and the inverter causes a complete system shut off (charging and discharging powers are then null). However, the system keeps using the battery to power its "auxiliaries" (see chapter No-load losses). Such a situation, if not monitored or detected, results in a significant battery discharge and can, if prolonged, cause irretrievable damage to the battery.
Re-establishing communication leads to an automatic system restart.
The loss of the communication link between the inverter and the outside has no effect. The system then applies the last instruction received (respecting the battery constraints).
If this instruction corresponds to a charging operation, this is not a problem since the inverter will meet the operating constraints of the battery. But if this instruction is a discharging operation, the battery will then be drained. It is therefore necessary to set a SOC (State Of Charge) minimum limit for inverter operation as permitted by the different configuration settings of the inverter.

- ***Battery management***

The charging and discharging laboratory tests of the battery showed that voltage and current parameters are respected in all configurations (Sunny Data Control software is used to give instructions to the inverter via the RS485 link):

- Installation: installation and setup must be done correctly
- Power: start charging at battery $P_{max}$
- Operation: put into operation by setting the parameter FedInSpntCom to Enable. Then sending instructions in real and reactive power by the parameters FedInPwrAtCom and FedInPwrRtCom (positive in discharge and negative in charge). These parameters are met in regards to the battery constraints.

A reservation can be made on the fact that every 6 months, a battery self test is performed (opening and closing of the electrical switch), but not taken into account today by the SMA inverter. That is why the installer will do a maintenance visit every 6 months to test the proper functioning of the electrical switch.

- ***Important operational characteristics***

  - ***Basic operation of the system***

It is possible to control the system operating point. The power is given in signed absolute value (positive for discharge, negative for charge). The nominal discharging power is 4600 W (nominal

power of the inverter) and the nominal charging power is 2000 W (maximum charging power of the battery).

- ***Precision compared to the given command***

The deviation of the measured power compared to the command given to the system is measured for different charge and discharge operating points. The accuracy of measurements is 5%.
We also measure the gap between the power displayed by the system and the command.
These measurements are made in steady state.

| Power instruction (W) | Deviation (measured power – command) / command (%) | Deviation (displayed power – command) / command (%) |
|---|---|---|
| **Discharge** | | |
| **2000** | 1.2 | 1.2 |
| **2300** | 2.7 | 0.7 |
| **2530** | 2.5 | 0.3 |
| **2760** | 4 | 0 |
| **3680** | 2.2 | 0.2 |
| **4600** | 1.2 | 0.8 |
| **Charge** | | |
| **1000** | 5.9 | 0.5 |
| **1050** | 7.2 | 2.9 |
| **1100** | 8.3 | 2.2 |
| **1300** | 3.9 | 0.5 |
| **2000** | 3.7 | 0.7 |

It can be seen that:

- In discharge, the system reaches perfectly its operating point (the deviation compared to the real measurement is in the sensor tolerance range)
- In charge, static error around 3% remains in some cases, which only represents a 30 W error.

- ***Measurements accuracy***

The deviation between the real measurement and the information sent by the system is given in the following table:

| Power instruction (W) | Deviation (measured power – displayed power) / displayed power (%) |
|---|---|
| **Discharge** | |
| **2000** | 0 |
| **2300** | 1.98 |
| **2530** | 2,72 |
| **2760** | 4.2 |
| **3680** | 2.5 |
| **4600** | 2 |

| | Charge |
|---|---|
| **1000** | 5.4 |
| **1050** | 4.2 |
| **1100** | 5.2 |
| **1300** | 3.45 |
| **2000** | 4.5 |

The deviation between the measured and the displayed values is in the tolerance range of the sensor. This shows that the power information displayed by the system is a good indicator (within 5%, which represents a 230 W error in the worse case).

- ***Response time***

The transition time from one operating point to another (in steady state) are measured with a 1 second tolerance.
The powers are positive in discharge and negative in charge.

| Initial power (kW) | Final power (kW) | Time (s) | Rate (kW/s) |
|---|---|---|---|
| **0** | 4.6 | 7 | 0.66 |
| **0** | -2 | 5 | 0.4 |
| **4.6** | -2 | 12 | 0.55 |
| **-2** | 4.6 | 14 | 0.47 |
| **4.6** | 0 | 7 | 0.66 |
| **-2** | 0 | 6 | 0.33 |
| **0** | 2.3 | 7 | 0.33 |
| **0** | -1 | 5 | 0.2 |
| **-1** | 2.3 | 9 | 0.37 |
| **2.3** | -1 | 10 | 0.33 |

The rate of change seems to be constant whatever the transition carried out (taking into account measurement errors).
We can note a pessimistic value 0.2 kW/s.
The previous measurements have been realized at a 60% state of charge. But this parameter does not seem to have a significant influence on the response times.

- ***Efficiency***

The efficiency of the energy storage system can be divided into three categories:

- The inverter conversion instantaneous efficiency
- The charge/discharge efficiency of the battery
- The consumption/losses of the system in waiting mode (no-load, no charge/discharge command)

**a. The inverter conversion instantaneous efficiency**

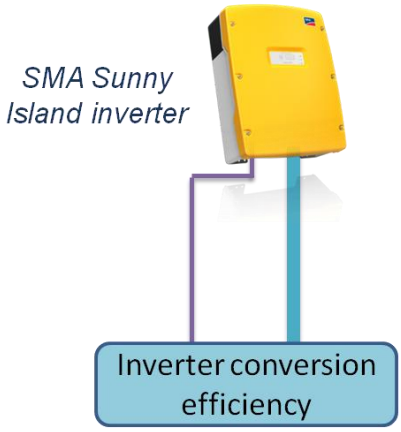



*Figure 66: Inverter conversion instantaneous efficiency*

The instantaneous conversion efficiency measurements between the AC and DC sides of the inverter are given in the following table:

| Power (kW) | Efficiency |
|---|---|
| **Discharge** | |
| **0.460** | 0.88 |
| **1.150** | 0.92 |
| **2.3** | 0.94 |
| **3.45** | 0.93 |
| **4.6** | 0.92 |
| **Charge** | |
| **0.2** | 0.76 |
| **0.5** | 0.88 |
| **1** | 0.94 |
| **1.5** | 0.96 |
| **2** | 0.96 |

These measurements are coherent with the data given by the manufacturer.

**b. The charge/discharge efficiency of the battery**

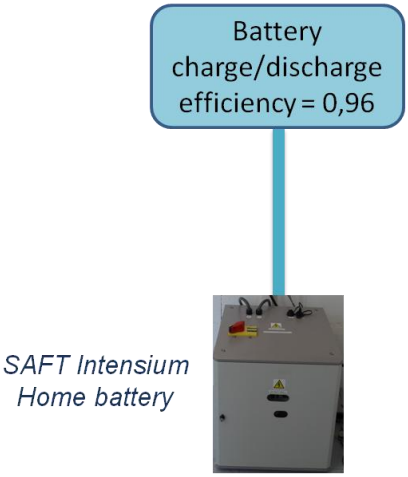



*Figure 67: Battery charge/discharge efficiency*

Tests have also been conducted to measure the charge/discharge efficiency of the battery. The result is that the battery efficiency is 0.96: if the battery is charged with 1 kW, it can then provide 960 W.

**c. The consumption/losses of the system in waiting mode (no-load, no charge/discharge command)**

The inverter consumption in waiting mode (no output power), with the remote control on, is around 40 W.
The battery BMM consumption is 7 W (manufacturer data). In the outdoor version, a small HVAC (Heating, Ventilation and Air Conditioning) is added to the battery resulting in a yet undetermined added consumption. The total battery consumption is estimated around 10 W but need to be measured.
Therefore, the total consumption of the energy storage system without any load is estimated around 50 W.

- ***Incidents recorded during the tests***

As of the date of this report, no incident has been recorded during the tests.

## 3.3.3 Conclusion

The results of the testing show a correct integration of the battery and the inverter. The operating constraints of the battery are fully taken into consideration and the system is controllable.
These results also give some important technical characteristics relevant to the design of the control system (response time, measurement precision, performances…).

### 3.3.4 External documents

*Figure 68: 13-2400-mu outdoor intensium home -v2 - fr.pdf*

Document Acrobat

*Figure 69: MPS-ZE-HK-VDE01261A1VFR13-fr-15 déclaration SMA conformité DIN.pdf*

## 3.4 Halfway assessment of the OLTC transformer

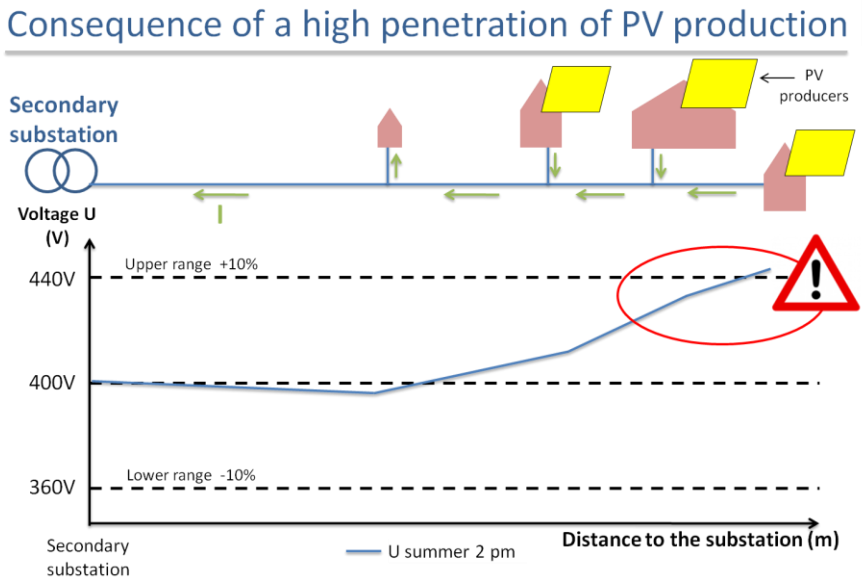
NICE GRID is a demonstration project which namely aims to facilitate the integration of massive PV production on low-voltage networks.

Indeed, this decentralised PV production creates constraints on the low-voltage networks. These constraints include increases in voltage in the production area. This happens mainly when the local production becomes largely superior to the local demand.

NICE GRID's purpose is to explore new ways of accommodating large amounts of PV production. This means designing and testing smart systems capable of managing these increases in voltage rather than systematically resorting to the crude solution that is the reinforcement of the network.

One of these systems is the on-load tap changing transformer (OLTC) also called 'solar transformer'. This kind of transformer is able to adapt its turns ratio (ie the ratio between the turns of the primary and secondary windings) without interrupting the supply. The OLTC transformer basically enables secondary substations to do something that all the French primary substations could do before which is modifying the ratio between the primary and secondary voltage. Typical secondary substation transformers also have several primary to secondary ratios, but they cannot move from one ratio to another while on load.

The final objective is to dynamically adjust the voltage at the transformer level to ensure that the voltage stays within the ranges defined by the 2007-1826 French decree (authorized limits of LV voltage at home) across the whole downstream distribution network.



### 3.4.1 Choice of the OLTC transformer in the NICE GRID project

- **Principle**

In France, voltage on the distribution network has to stay within the 230V +/- 10% range. The low-voltage network is radial and, historically, current goes from upstream to downstream as there are more loads than power sources connected at this level.

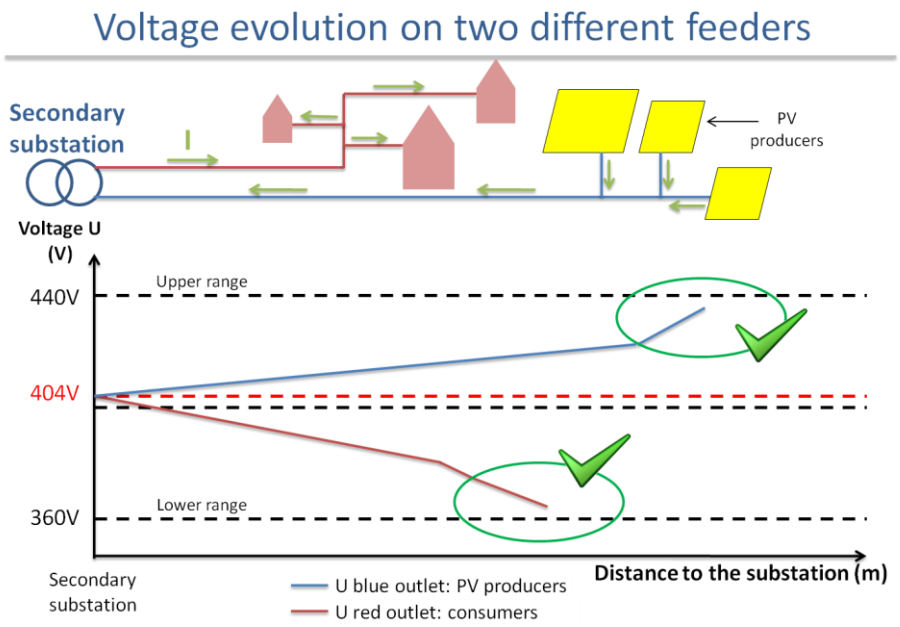
The development of PV production is challenging this principle. Indeed, while the demand still outweighs the production in the evening, the PV production can be higher than the demand during the day. This means that some low-voltage network with a high penetration of PV production can now regularly experience both increases and decreases in voltage on the same day.

The OLTC transformer's objective is to maintain the voltage within the +/- 10% range at all time by adapting its primary to secondary voltage ratio. The NICE GRID projects aims to replace a classic 20kV/400V transformer by a 20kV/400V OLTC transformer.

- **Adaptation to variations of the primary voltage**

The OLTC transformer can be an asset to a distribution network with a high penetration of PV production as it can provide a constant secondary voltage by adapting its turns ratio to the variations of the primary voltage. On a distribution network fitted with a classic transformer, the +/- 10% range has to cater for both medium and low voltage variations. This can prove difficult as the MV network voltage can vary up to +/- 5%, thus leaving only a small range of acceptable variations for the LV network. The objective of the OLTC transformer is to compensate these medium voltage variations in order to leave the complete +/- 10% range for the variations on the low voltage network.

Take a substation with two feeders that has to supply both consumers generating a 10% decrease in voltage and producers generating an 8% increase in voltage. The transformer of this substation should be set to provide 400V +1% as a secondary voltage at all time. As shown by the figure below, this would ensure that the voltage is always maintained within the 400V +/-10% range. However, this figure also shows how important it is to maintain the 400V +1% secondary voltage constantly as any variation of that voltage could result in an irregular variation of the voltage at the end of one of the feeders.




The provision of a constant secondary voltage is where the OLTC transformer is required. Indeed, it is able to dynamically adjust its primary to secondary ratio depending on the variations of the primary voltage. The French voltage plan of 2011 plans for variations at different levels: the primary substation, the medium voltage network and the secondary substation – extreme variations are given in the table below.

| **Voltage variations (extreme)** | **Summer** | **Winter** |
|---|---|---|
| Primary substation | 2% | 2% |
| Medium voltage network | 5% | -5% |
| Secondary substation | 2% | -2% |
| **Total primary voltage variation** | **9%** | **-5%** |

This table means that the primary voltage of the transformer could vary between 20kV - 5% and 20kV +9%. Thus, to ensure that it can provide a constant 400V +1% secondary voltage, the OLTC transformer should be able to operate in the -8%/+6% range around the 20kV/400V transformation ratio or +/-7% range around the 20kV/404V transformation ratio.

This example would have been extremely difficult to tackle with a classic transformer, as the secondary voltage variations (-10%/+8%) added with the primary voltage variations (-5%/+9%) exceed the acceptable +/-10% range. This highlights the potential of OLTC transformers for solar districts (districts with a high penetration of PV production).

- **Adjustment intervals**

The OLTC transformer operates on a 14%-wide range. There is a finite number of taps on the winding that define which ratios within this -8%/+6% range (around the 20 kV/400V ratio) can be selected.

The interval between the different taps is an important issue. A large interval could affect the quality of the power and the devices connected due to the important variations of the voltage when the transformer changes the tap position. A small interval would multiply the number of taps and affect the cost and the maintenance of the system.

Usually, the interval between the taps in a transmission transformer is 1.5%. For other distribution OLTC transformers, intervals are comprised between 1.5% and 2.5%. These intervals do not create any issues for the downstream customers when the transformer changes from one tap to the next.

We decided to settle for a 2% adjustment interval which would have resulted in the use of 8 taps to cover the -8%/+6% range. However, it appeared that the common number of taps on an OLTC distribution transformer is 9. We decided to make the most of this and to add a 2% margin at the higher end of the operation range. This means that our OLTC transformer ends up converting a primary voltage of 20kV +/-8% into a secondary voltage of 400V +1% (see table on the next page).

Comparing this table with the next page figure of a classic transformer technical specifications is a good way of summarising the differences between a classic transformer and an OLTC transformer. Indeed, it highlights the fact that an OLTC transformer can adapt to a larger spectrum of primary voltage. Moreover, the OLTC transformer will adapt more accurately to these primary voltages than a classic transformer and, finally, it will do so while ‘on-load’.

*Primary taps and associated primary to secondary ratios of the OLTC transformer*

| Primary voltage | Secondary voltage |
|---|---|
| **21 600 V** | **404 V** |
| **21 200 V** | |
| **20 800 V** | |
| **20 400 V** | |
| **20 000 V** | |
| **19 600 V** | |
| **19 200 V** | |
| **18 800 V** | |

| | |
|---|---|
| **18 400 V** | |

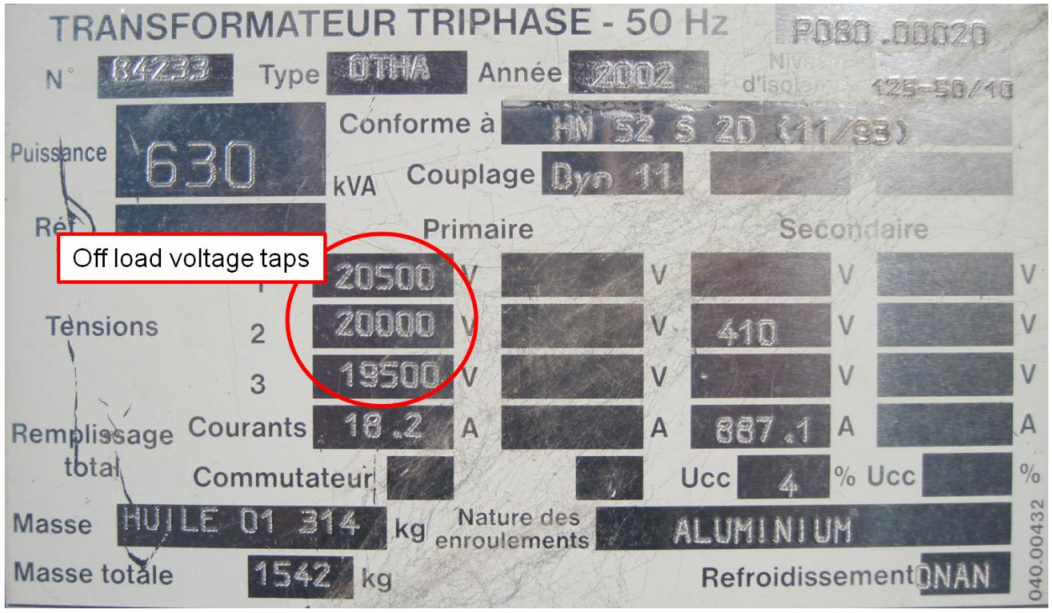



*Figure 70 - Classic transformer technical specifications*

## 3.4.2 Integration of the OLTC transformer to the project

- **Integration to the intelligence of the project**

The OLTC transformer has two different operating modes in the project:

1) Autonomous operation

On its own, the OLTC transformer uses sensors to measure the primary voltage and then select the correct tap to deliver the fore-mentioned 400V +1% secondary voltage.

2) Integration to the Network Energy Manager

The OLTC transformer is able to receive commands from the project's Network Energy Manager (NEM). The NEM can thus feed the transformer a schedule of voltage set points. The OLTC transformer will follow these set points and deliver a specific secondary voltage.

The link with the Network Energy Manager will be provided by a communicating box from ALSTOM that will use a BPL (Broadband Power Line Carrier).

- **Integration of the OLTC transformer to the grid**

To test the potential of this kind of transformer, it is important to select a secondary substation where a classic transformer could have trouble maintaining the voltage in the +/- 10% range. These substations are characterised by important variations of voltage on both the medium and low voltage networks. Hence, the typical candidate would be a secondary substation connected far from the primary substation with a long LV network, volatile consumers and some producers. This type of substation will maximise the use of the tap changer to adapt the primary to secondary voltage ratio of the transformer in real time.

Given the current repartition of the transformers power in the “Méditerranée” area, the OLTC transformer is going to be a 400 kVA transformer. Due to the additional devices required for the OLTC feature, the transformer will take more space than a classic 400 kVA transformer. Its size will be somewhere between a 400 kVA and a 630 kVa transformer.

## *3.4.3 Development and installation of the OLTC transformer*

- **Current state of development**

Given the specifications stated earlier in this report (400kVA, 20 000kV/404V +/- 8%, 9 taps), the project selected the OLTC transformer Minera – a model developed by SCHNEIDER ELECTRIC. The tap changer used is the iTAP by MR (Maschinenfabrik Reinhausen); it is capable of 700.000 operations before maintenance is required. Pictures of the transformer during its development are available below.

*Figure 71 - regulation box of OLTC transformer*

*Figure 72 - Built OLTC transformer*

ERDF and SCHNEIDER ELECTRIC are currently running tests on the OLTC transformer in order to make sure that it will be reliable both in its transforming role and in its voltage maintaining one. Its installation and first operation are scheduled to take place in September 2014 in autonomous mode. The remote operation of the OLTC transformer should be implemented before summer 2015. The finished product should look like the picture below.

- **Future location of the transformer**

Seven solar districts [21]have been identified in the Nice Grid project: Cailletiers, Colombie, Docks Trachel, Lou Souleou, Pesquier, Plaine 1 and Rosemarines. They are the districts where the summer experiments that deal with the integration of PV production take place.

They all correspond to districts where the high penetration of PV production is likely to create constraints on the network and, thus, were logical candidates to the installation of the OLTC transformer.

[21] A solar district is a secondary substation and its corresponding customers

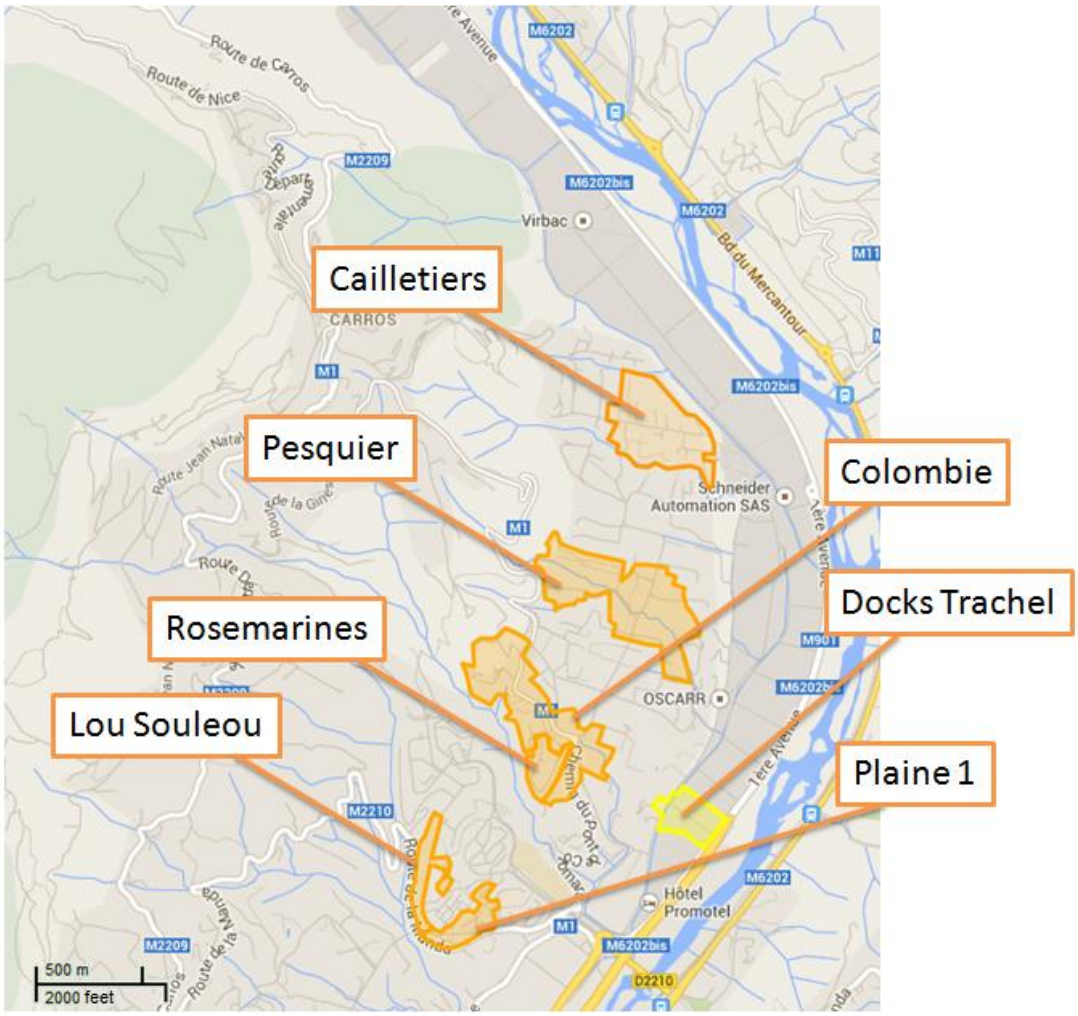



*Figure 73 - Location of the main solar districts*

In the end, the Cailletiers district was selected as the location of the OLTC transformer currently under development. This district is a typical example of a residential area with multiple single-family detached houses and a total of around 120 customers. The low voltage feeeders can be as long as 500 meters and consist in both underground and overhead lines of various cross-sections. These features all increase the likelihood of the apparition of constraints on the low voltage network, constraints that could be alleviated by the OLTC transformer.

- **A look at the Cailletiers substation and at the future implantation of the OLTC transformer**

Pictures of the prefabricated building housing the Cailletiers substation are located below. Two doors allow access to the interior, the one on the right gives direct access to the transformer while the one on the left leads to the MV connectors, the LV feeders and the metering equipments.

*Figure 74 - Entrance of Cailletiers secondary substation*

*Figure 75 - Photo of the actual transformer at Cailletiers secondary substation*

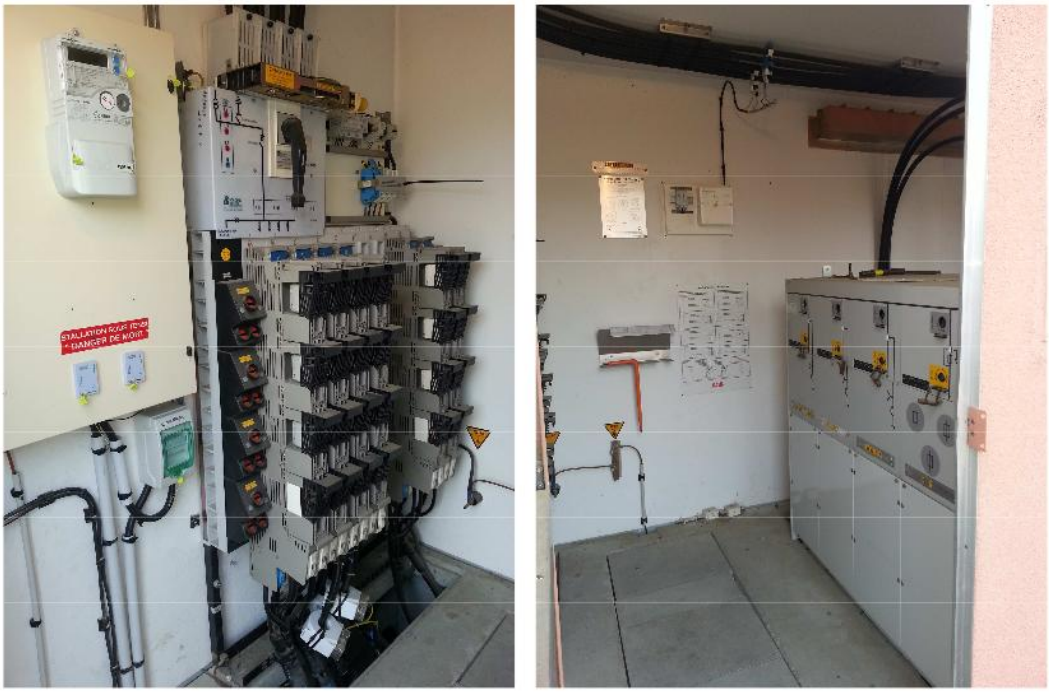


*Figure 76 - Photo of Cailletiers secondary substation*

The transformer of this substation is currently a 630 kVA transformer but it is oversized and a 400 kVA OLTC transformer will be enough. The fact that the building currently accommodates a 630 kVA transformer assures us that it will be large enough for a 400 kVA OLTC transformer even though the OLTC modifications make it slightly bigger than a classic 400 kVA transformer.

The detailed technical specifications of the current transformer are included in Section 2.3 (last figure of the section), it has a transformation ratio of 20 kV/410V with three taps that give it a +/- 2,5% operation range – however those taps cannot be changed on-load. Moving to a 20 kV/404V +/-8% OLTC transformer will thus clearly improve the performances of the substation.

The figure below displays the schematics of the future installation, including the cables that will pass underneath the technical raised flooring.

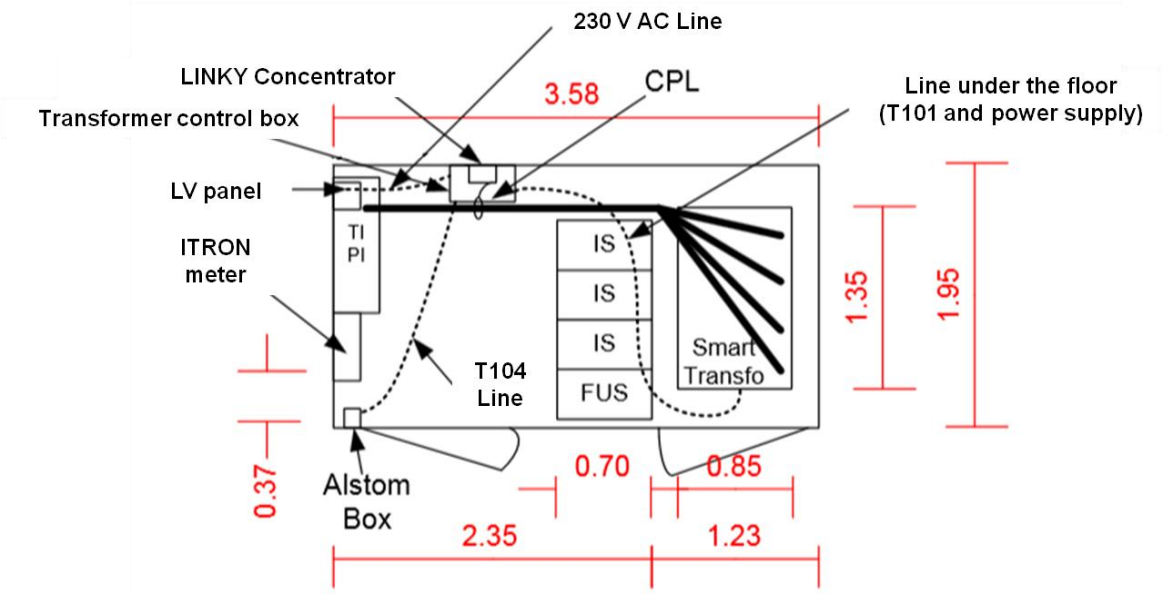



*Figure 77 - Plan of the Cailletiers secondary substation*

TIPI: General LV distribution panel

IS: Switches

FUS: Fuse

## 3.4.4 Conclusion

The on-load tap changing transformer that is going to be used in the NICE GRID project will be responsible for the delivery of a constant secondary voltage of 404 V when running autonomously. It will thus adapt to any variation of the primary voltage and adjust its primary to secondary voltage ratio accordingly.

It will be able to fulfil this role autonomously but will also be fitted with a communication device so that it is integrated as an extra flexibility source in the Network Energy Manager of the project. When commanded to do so by the NEM, it will follow a planning of voltage set points instead of just maintaining a constant secondary voltage.

The transformer that will be used in the project will be able to operate on a -10%/+6% range around the 20 kV/400 V ratio. This means that the transformer will be able to cope with primary voltages between 18 000 V and 21 600 V and still deliver a 404 V secondary voltage. To do this, it will be fitted with 9 taps, each of them will correspond to a 2% step.

The OLTC transformer's power will be 400 kVA but the transformer could take up as much space as a 630 kVA transformer due to the additional devices.

It will be installed by September 2014.

# 4. Assessment of the PV onsite installation

This section presents a review of PV installations to date, a progress report on the recruitment of participants in PV management experiments, and, finally, a summary of the tests carried out to validate the battery management solution proposed for storing the electricity produced by these panels.

This section consists of three parts:

7.1: Description of the measures adopted to facilitate the acquisition of photovoltaic panels and review of installations performed.

7.2: Description of EDF offers for PV management and initial recruitment results

7.3: Description of the tests carried out to validate the battery management solution deployed within the framework of the NICE GRID project.

| | |
|---|---|
| PA: | EDELIA gateway |
| PFD: | EDELIA Remote platform to control the inverter |
| TIC: | Customer remote information output of an ERDF electronic meter |
| SOC: | State Of Charge (as %) of the battery |
| SOH: | State Of Health of the battery |
| SRC: | Sunny Remote Control |
| EDELIA | EDF subsidiary |
| EDF | French utility |
| CSTB | Building Scientific and technical research center |

# 4.1 Review of the PV implementation process and of PV installations performed

## 4.1.1 NICE GRID: an ambitious photovoltaic power project on a voluntary basis

The demonstrator has ambitious objectives for integration of photovoltaic power and demand response capacity in Carros commune.

Since participation in the project is on a voluntary basis, EDF has worked out a recruitment process to bring together the largest number of participants and to insure the quality of PV panels.
ERDF has defined six geographic areas, called "solar districts" (about 500 residential housing), covered by the experiment, and EDF has endeavoured to identify potential participants in the project according to this breakdown. The objective of a solar district was to have 30% of the district consumption bring by solar electricity production (depending on the district this objective was represented 8 to 20 new PV producers to recruit).

To perform this recruitment, EDF put in place a communication campaign targeted on the inhabitants of these six districts and selected and designed a technical and financial support offer for private individuals wanting to become equipped.

For EDF the aim was in particular to facilitate the acquisition of photovoltaic panels in the context of the project by providing:
Technical aspects:

- Technical quality of the photovoltaic installation set up on their houses;
- Certification and commitment of the suppliers and installers of these installations.

Information aspects:

- The forecast return on capital employed for these installations;
- Neutrality with regard to a panel of installers and the choice of installer.

## 4.1.2 Recruitment process established by EDF

The recruitment process established by EDF for the customer assistance scheme with the support of building scientific and technical research centre CSTB is described briefly below:

- Identification of potential customers in the six "solar districts";
- Establishment of a panel of photovoltaic panel installers who meet quality criteria defined in cooperation with the CSTB;
- Definition of communication strategy and the associated resources (workforce, communication tools, events, incentives, etc.);
- Launch of the recruitment campaign;
- Analysis and processing of potential customers;

- Promoting the EDF commercial offer with the assistance of the CSTB;
- Customer agreement, signature of agreements, execution and commissioning of photovoltaic installations and ecosystem.

### 4.1.3 Description of the "Smart solar equipment" offer

The aim was to facilitate customers' acquisition of a photovoltaic installation together with a battery throughout the period of the NICE GRID experiment.

Under the NICE GRID experiment, therefore, EDF proposes:
Financial aid of up to €6,000. This amount, capped at €6,000, is designed to reduce the payback period of PV panels by six years. It depends on the photovoltaic panel installation that will be executed (amount, production potential, etc.). This aid is awarded to the first 50 signatories of the quote by a PV installer supporting the project, and the experiment agreements. This offer was valid until 31 July 2014. Results are presenting in 2.11 paragraph.
**Assistance** provided by an independent organization, Centre Scientifique et Technique du Bâtiment (CSTB).
A choice of several commercial proposals by installers who are signatories of a cooperation agreement with EDF within the framework of the NICE GRID project.
**Free connection** of your installation to the electricity grid.

The offer also proposes:

- A new source of income: the electricity produced by the photovoltaic panels is bought by EDF at the price applicable throughout the period of the buyback agreement.
- A least-cost power reserve, stored at an attractive off-peak-hour price (during maximum sunlight hours[22] or during the night[23]) in a battery installed on the customer's premises. The battery is free of charge for the period of the experiment (from December 2014 to September 2015).
- Electricity consumption at an attractive price between 12 pm and 4 pm during the 40 sunniest days of the summer of 2014 and then the summer of 2015.
- Free, detailed monitoring of solar power consumption and production via an online service offered throughout the period of the experiment.
- A digital tablet offered[24] to thank the customer for becoming a Consum-actor of the energy system.

### 4.1.4 Definition and establishment of the specifications for PV installers

[22] *For customers having the base-load option or the peak hour/off-peak hour option.*
[23] Only for customers having the peak hour/off-peak hour option.
[24] *Tablet delivered after installing the battery.*

The identification and application of a multiple-criterion analysis makes it possible to build specifications ensuring transparent selection of installers. Based on a normative and certification approach, this analysis makes it possible, by quality indicators, to select the minimum prerequisites that must be met by applicants for the project. The indicators or selection criteria were defined so as to be transparent, objective and non-discriminatory for the installers.
The results of this action take the form of specifications, which were validated by a selected panel of professionals in February 2013 in order to ensure a good match between objectives and certification.
The establishment, implementation and method of dissemination of these specifications were explained at the public meeting that EDF Commerce-Méditerranée organized in February 2013 with the support of building scientific and technical research centre CSTB. There was no technical requirement for PV modules quality. But :

- the French regulation gives some payback if the PV panels are incorporate to the building
- the CSTB had to make a verification of the conformity of the PV electricity production giving by the installer and regarding to PV modules installed

### 4.1.5 Identification of solar potential and site analysis

The solar potential of the six districts identified within the framework of the project was determined in order to classify the expected levels of production potential. The aim was to validate the estimates of the professionals who reply to the specifications (cf. §3). The results thus obtained can therefore partially ensure evaluation of the proposed dossiers, complementing the checks described in §2.4.

### 4.1.6 Definition and application of a set of technical requirements for potential customers

A questionnaire was produced to identify all the technical and practical criteria of the sites receiving a photovoltaic installation. This questionnaire should enable installers to make a "blind" estimate for the installations they have to execute without favouring anyone. It can thus be used to place installers in competition with one another. It is the quality of the dossiers presented that should be used as the criterion for selection by the customer. Customers can then contact the installer of their choice.

This questionnaire is built in three sections. The first section covers the structure/roof covering part, the second section the electrical safety and sizing part, and the last section the electricity generation, storage and energy part.

These three criteria make it possible to build the questionnaire but above all they allow collection of all the information needed by the installers. The questionnaire was validated by the professionals to ensure its consistency at a meeting held with the PV installers.

Collection of the data needed by the installers to produce quotes is performed by the CSTB.

### 4.1.7 Verification of the conformity of the technical proposals with the project criteria

This verification aims to analyse and evaluate the conformity of all the installers' dossiers with the requirements of the specification criteria (cf. §3) - objective and non-discriminatory criteria, and to analyse and evaluate the conformity of all the proposals/quotes produced with the criteria of the technical requirements questionnaire (cf. §5) - objective and technical criteria. An evaluation is also made of the consistency of the proposal with the production potential expected when identifying the solar potential (cf. § 4).

The technical proposals are compiled by the CSTB from the database built beforehand. The CSTB ensures compliance with the commitments made by the installers within the framework of the experiment (including response times, for example).

### 4.1.8 Verification of conformity of the proposals with the work performed

This procedure concerns deployment of the technical solutions selected by customers on the identified sites. Since the stated will of the CSTB is to ensure continuity in this project, worksite checks and audits are performed randomly during the works to check the consistency between the proposals and the installed items, as well as checks and audits upon delivery of said items.

This action ensures the effective quality of the installations executed with a view to efficiency and exemplarity of the installations executed within the framework of the project.

### 4.1.9 Establishment of a panel of NICE GRID installers with specific specifications for the NICE GRID requirements

Work performance is still a major subject of concern for private customers who want to install photovoltaic panels on their roof.

So as to reassure them, and in light of the context surrounding the photovoltaic power market, EDF decided, with the support of the CSTB, to establish a panel of industrial installers capable of meeting requests for the implementation of photovoltaic installations that EDF is going to promote.

These installers had to comply with the specific criteria and requirements worked out by the CSTB, and sign a commitment charter.

To establish this panel of installers, the CSTB provided EDF with the list of all the companies present in this market, the list of PV trade associations and non-profit organizations, certification organizations and the French environment and energy management agency "ADEME", as well as business magazines. EDF inserted in these publications an advertisement announcing a public meeting to present the NICE GRID project, this meeting was open to all PV installers.

In addition to this announcement, and to mobilize the professionals, EDF sent each of them a letter of invitation to this event.

Following this meeting, the interested installers complying with the criteria signed a commitment charter, called a Collaboration Agreement, and became privileged interlocutors of those taking part in the experiment.

### 4.1.10 Formalization of EDF's commitment to its customers taking part in the NICE GRID experiment

Following the communication and recruitment campaigns, inhabitants of Carros expressed interest in joining the NICE GRID project.

These candidates for the experiment had personalized contacts with the EDF sales teams. They then benefited from the assistance process described in section 2, with a view to having photovoltaic panels installed on their roof. They received a visit by the CSTB and quotes from photovoltaic installers approved by the CSTB, and when they took their decision to effectively undertake the panel installation work, EDF proposed to them drawing up an Agreement on participation in the NICE GRID experiment.

This agreement specifies the respective commitments and responsibilities of the two parties, throughout the duration of the project, and in particular:

- The reference of the quote indicating the equipment that will be installed;
- The financial assistance granted by EDF and its method of payment;
- Access to the electricity consumption and production data of the participant customers;
- The confidentiality of customer data;
- Measures to be taken if the customer no longer wanted to take part in the project;
- Measures to be taken if the customer wanted to sell their house.

### 4.1.11 PV installations performed and feedback

The implementation process of the PV panels was satisfactory on the following points:

- In its technical assistance measures, the support of the CSTB is a major asset for EDF.

This support is a real guarantee of trustworthiness and neutrality which encourages customers to agree to take part in the project.

- In the content of the commercial offer aiming to reduce the payback period for the PV installation to at most 6 years;
- In performance of the works, since worksite visits and audits effectively made it possible to eliminate negligent installers and nonconforming equipment.

However, the economic and political environment is not conducive to PV installation. The electricity buyback price fell constantly during the first two years of the project, as well as the tax credit from which customers benefit.

The great majority of the identified potential customers intend to materialize their choice of PV equipment. For the 24 customers identified, the ratios are as follows:
- 30% signed the agreement with EDF and are or will be equipped with PV panels;
- 46% customer's decision pending:
- 13% dossiers in the process of invitation to tender from the panel of installers;
- 11% did not follow up.

These few customers, identified by EDF as potential customers, then assisted according to the scheme, in the end did not materialize the installation of photovoltaic panels on the roof of their house. The reasons why these customers pulled out are of two orders:
- financial, because the cost of the customer's investment is not compatible with their available cash at the time (about 5000 to 6000€);
- technical, because in most situations it is necessary, to confirm incorporation in the building, to cut out the under-tile sheeting, and this can create fragility in the roof waterproofing system.

Moreover, the gestation of a potential customer's dossier takes a relatively long time given the various stages required until the customer's final decision-making process. Three main periods can be noted.

The first period involving setting an appointment for the CSTB's technical visit, taking into account the timetables of the customer and the CSTB and weather conditions, covers about fifteen days.

Then, compilation of the technical dossier after the visit, sending it to the installers, the time allotted for their replies, analysis on return by the CSTB and, finally, sending to EDF for transmission to the customer takes around five weeks.

Finally, the customer's decision is subject to two constraints: the timetables of the installers selected for the visit for physical confirmation of their quote, and the season, since it is not always possible to know the electricity buyback price because this price, revised each quarter, is announced only once the quarter is well underway.

Accordingly, everything combined, the time elapsing between identification of a potential customer and their signature of the agreement can be as much as around three months.

So we couldn't reach the objective for all the solar districts (30% of the district electricity consumption is bringing by the PV electricity production) but we reach it for 3 of them.
Two districts will benefit of a production of 24kWc for one (hostel) and an additional 140kWc for the other one (enterprise). The last district is expected to benefit 18kWc (6 housings).

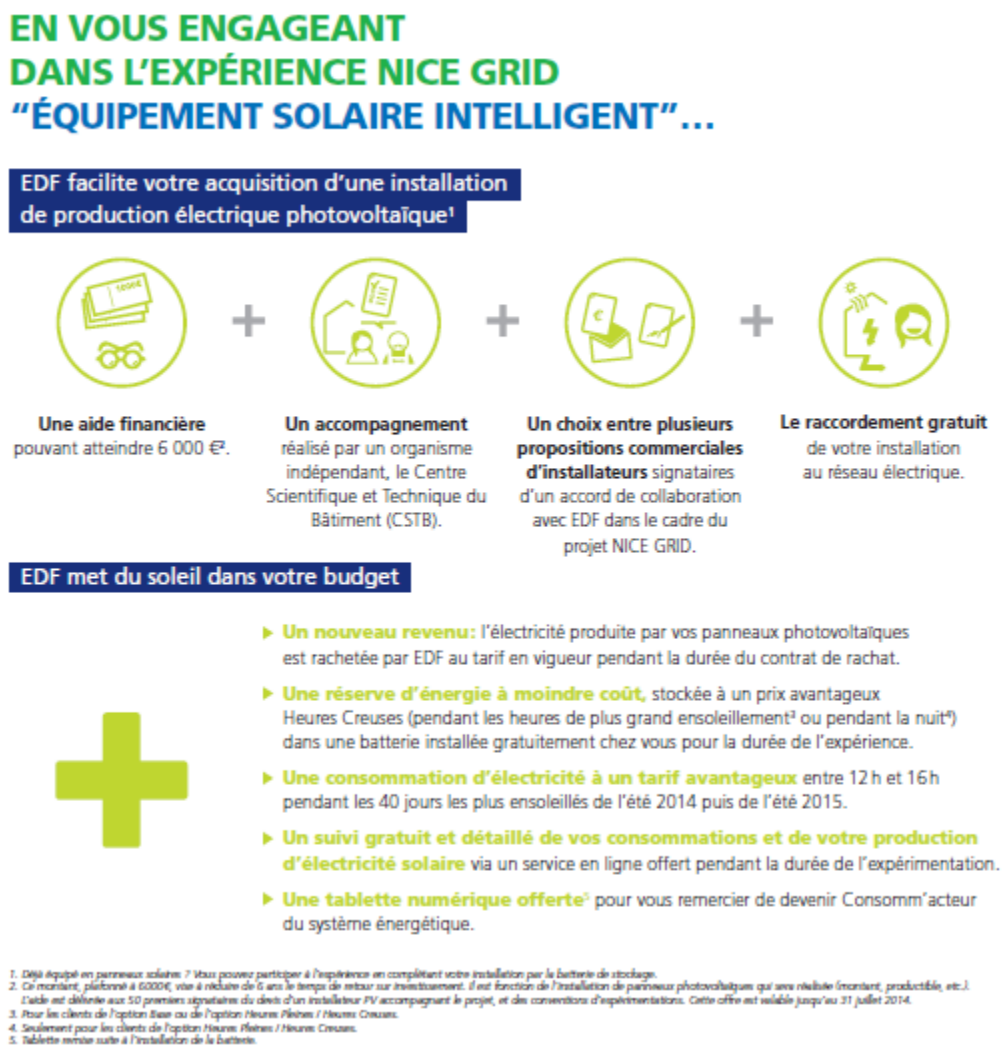
## 4.1.12 Main documents used in the process

Communication document: I AM A CONSUM-ACTOR IN THE SMART SOLAR DISTRICT. Guide of the CONSUM-ACTOR explaining instructively the potential benefits of demand management.

JE SUIS
CONSOMM'ACTEUR
DU QUARTIER SOLAIRE INTELLIGENT
dès lors que j'habite Carros dans un des quartiers solaires intelligents et que je suis équipé de :
Compteur Linky
et
Panneaux photovoltaïques
et/ou
Batterie
et/ou
Ballon d'eau chaude
Mes usages électriques sont :
Éclairage
et/ou
Multimédia
et/ou
Électroménager
et/ou
Chauffage électrique
NICE GRID, c'est chez moi, dans mon quartier !
Grâce à l'installation de panneaux photovoltaïques et de moyens de stockage d'énergie, je peux participer* à une nouvelle génération de quartier solaire intelligent.
* La participation à l'expérimentation dépend d'un ensemble de conditions d'éligibilité à remplir par le Participant. En fonction du profil, différentes modalités de participation à NICE GRID pourront être proposées.

Communication document: A brochure presenting the "Smart solar equipment" offer described in section 4.

EXPERIENCE 3
ÉQUIPEMENT SOLAIRE INTELLIGENT
EDF
FAITES L'EXPÉRIENCE
D'UNE GESTION INTELLIGENTE
DE L'ÉLECTRICITÉ SOLAIRE
EN 2014 ET 2015 !
L'EXPÉRIMENTATION NICE GRID,
C'EST À CARROS DANS VOTRE QUARTIER.
DEMANDEZ DÈS MAINTENANT À BÉNÉFICIER
D'UN ACCOMPAGNEMENT ET D'UN SOUTIEN
FINANCIER D'EDF POUR DEVENIR
PRODUCTEUR-STOCKEUR D'ÉLECTRICITÉ.
NICE GRID



EN VOUS ENGAGEANT
DANS L'EXPÉRIENCE NICE GRID
"ÉQUIPEMENT SOLAIRE INTELLIGENT"…

EDF facilite votre acquisition d'une installation de production électrique photovoltaïque[1]

**Une aide financière** pouvant atteindre 6 000 €[2].

**Un accompagnement** réalisé par un organisme indépendant, le Centre Scientifique et Technique du Bâtiment (CSTB).

**Un choix entre plusieurs propositions commerciales d'installateurs** signataires d'un accord de collaboration avec EDF dans le cadre du projet NICE GRID.

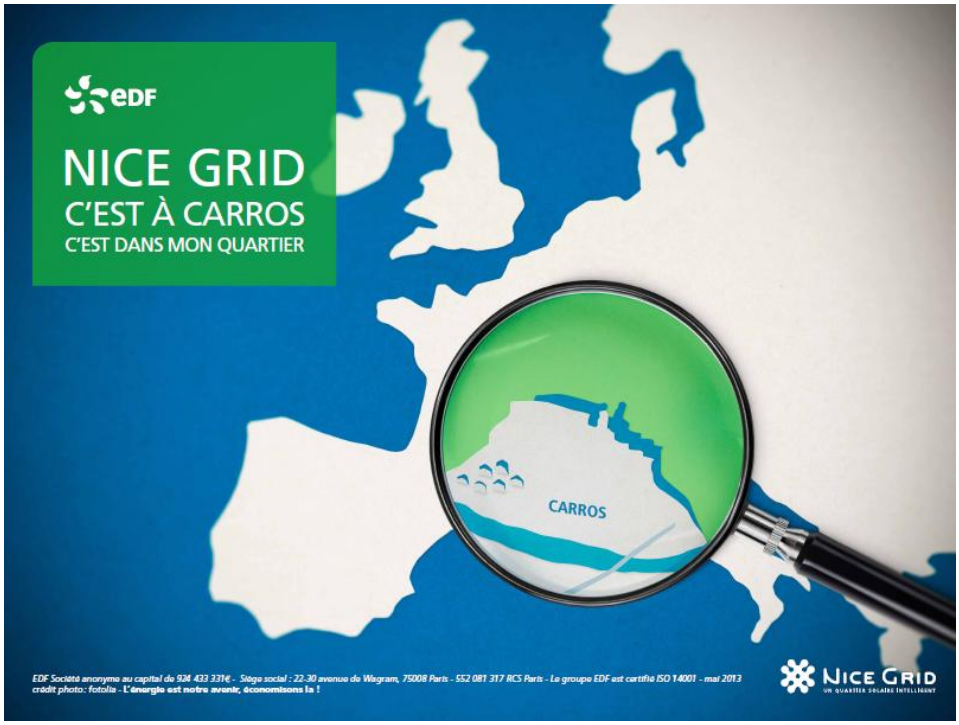
**Le raccordement gratuit** de votre installation au réseau électrique.

EDF met du soleil dans votre budget

- **Un nouveau revenu:** l'électricité produite par vos panneaux photovoltaïques est rachetée par EDF au tarif en vigueur pendant la durée du contrat de rachat.
- **Une réserve d'énergie à moindre coût,** stockée à un prix avantageux Heures Creuses (pendant les heures de plus grand ensoleillement[3] ou pendant la nuit[4]) dans une batterie installée gratuitement chez vous pour la durée de l'expérience.
- **Une consommation d'électricité à un tarif avantageux** entre 12 h et 16 h pendant les 40 jours les plus ensoleillés de l'été 2014 puis de l'été 2015.
- **Un suivi gratuit et détaillé de vos consommations et de votre production d'électricité solaire** via un service en ligne offert pendant la durée de l'expérimentation.
- **Une tablette numérique offerte**[5] pour vous remercier de devenir Consomm'acteur du système énergétique.

1. Déjà équipé en panneaux solaires ? Vous pouvez participer à l'expérience en complétant votre installation par la batterie de stockage.
2. Ce montant, plafonné à 6000€, vise à réduire de 6 ans le temps de retour sur investissement. Il est fonction de l'installation de panneaux photovoltaïques qui sera réalisée (montant, productible, etc.). L'aide est délivrée aux 50 premiers signataires du devis d'un installateur PV accompagnant le projet, et des conventions d'expérimentations. Cette offre est valable jusqu'au 31 juillet 2014.
3. Pour les clients de l'option Base ou de l'option Heures Pleines / Heures Creuses.
4. Seulement pour les clients de l'option Heures Pleines / Heures Creuses.
5. Tablette remise suite à l'installation de la batterie.

Communication document: Notices in the town of Carros to raise inhabitants' awareness of the project.


EDF
NICE GRID
C'EST À CARROS
C'EST DANS MON QUARTIER
CARROS
NICE GRID

## 4.2 Offers proposed by EDF to customers to encourage the introduction of PV

The massive introduction of new energies such as photovoltaic power on the grid creates new challenges for the electrical system, which must adapt to receive these forms of production, which are intermittent and erratic.

Strengthening the grid or building production facilities which would back up the intermittent production sources would be possible solutions, but they are expensive for the community.

In the NICE GRID project, we are in fact testing an alternative, which involves adapting consumption to production, and not the opposite as was done in the "incumbent" system. To achieve this, the customer is invited to play a far more active role interacting with the network.

Within the framework of the NICE GRID project, EDF proposes to its customers in Carros, private individuals or businesses, to take part in this ambitious project which announces the city of tomorrow.

Concretely, EDF presents consumers of the 6 solar districts with 3 offers or "experiments" to take part in a new generation of smart solar districts:

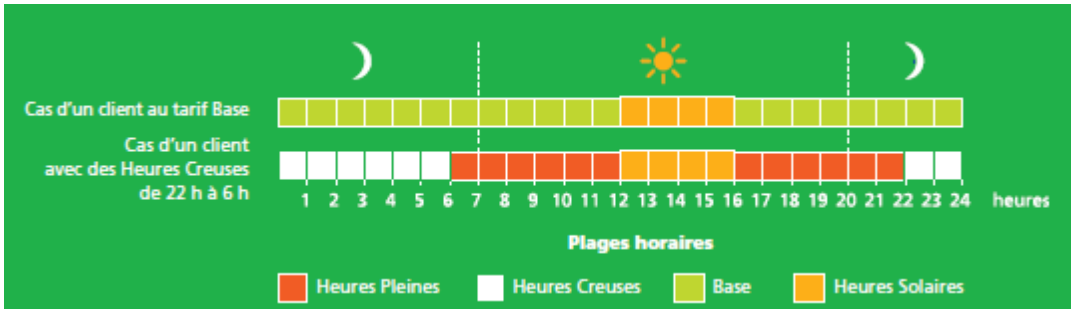
- Solar bonus
- Smart hot water cylinder
- Smart solar equipment.

### 4.2.1 Description of the offers

- **Solar bonus**

During the 40 "solar days" of the summer of 2014 and then the summer of 2015, indicated the day before by SMS and/or e-mail, the district produces more electricity than it consumes between 12 pm and 4.00 pm. EDF invites customers in this experiment to shift their electricity consumption to these hours, called "solar hours". At the end of each summer, EDF pays a gift cheque[25] enabling the customer to benefit from a price equivalent to off-peak hours for their electricity consumption during the Solar Hours.

[25] The amount of this gift cheque is calculated according to the following formula: the difference between the peak hour or base-load price of your electricity supply contract and the off-peak-hour price applied to your electricity consumption from 12 pm to 4.00 pm during the Solar Days. In all cases, customers continue to pay for their electricity consumption from 12 pm to 4.00 pm at the price indicated in their electricity supply contract. The prices can be looked up on the "particuliers.edf.com" website.


Cas d'un client au tarif Base
Cas d'un client avec des Heures Creuses de 22 h à 6 h
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 heures
Plages horaires
Heures Pleines
Heures Creuses
Base
Heures Solaires

- **Smart hot water cylinder**

EXPERIENCE 2
BALLON D'EAU CHAUDE INTELLIGENT
EDF
FAITES L'EXPÉRIENCE D'UNE GESTION INTELLIGENTE DE L'EAU CHAUDE SANITAIRE EN 2014 ET 2015 !
L'EXPÉRIMENTATION NICE GRID, C'EST À CARROS DANS VOTRE QUARTIER. DEMANDEZ DÈS MAINTENANT À BÉNÉFICIER D'UN TARIF AVANTAGEUX DE L'ÉLECTRICITÉ AUX HEURES OÙ L'ÉLECTRICITÉ SOLAIRE EST PRODUITE EN ABONDANCE.
NICE GRID

The "SMART HOT WATER CYLINDER" experiment began in June 2014. Why is it smart? It's smart because it will be charged automatically at the times when the district's panels are productive (about 40 days from 1 May to 30 September), thereby preventing excess production which could result in some solar panels being disconnected from the electricity grid. This recharging takes place in addition to its normal operation at night, so there is no impact on the customer's comfort. And

since abundant energy is then available in the district ("peak production"), customers benefit from an electricity price between 12 pm and 4.00 pm equivalent to the off-peak-hour price so as to encourage them to also shift their consumption to these so-called "solar" hours.

- **Smart solar equipment**

The "SMART SOLAR EQUIPMENT" experiment encourages the customer to become equipped with photovoltaic panels thanks to technical assistance from the CSTB to contribute to the quality of the installations, and financial aid. This aid is granted for the PV installation and a storage solution of the electric battery type provided by partner SAFT. This battery can store electricity at times when the panels are most productive, to consume it later. Here again the customer benefits from an electricity price reduced to the off-peak-hour price for their electricity consumption from 12 pm to 4.00 pm on "solar" days so as to encourage them to consume when there is excess production, or else store it.

The so-called "solar" days are indicated to the customer by EDF the day before by SMS message or email.

Each participant is entitled to detailed monitoring of their electricity consumption and their production where applicable.

### 4.2.2 Results obtained for the first summer 2014:

The results for the first summer (as at 31 July 2014) are as follows (recruitment on 475 inhabitants):

| | | Verbal agreements | Written agreements | Active[26] |
|---|---|---|---|---|
| SUMMER | Smart solar equipment (PV + battery) | 24 | 6 (agreement for PV installation)<br>Battery agreement at signature of customers in October 2014 | - |
| | Smart hot water cylinder (cylinder management via Linky) | 30 | 25 | 24 |
| | Solar bonus | 44 | 37 | 36 |
| | TOTAL | 98 | 68 | 60 |

Recruitment is continuing, in particular via a sponsorship campaign to reach about one hundred consum-actors in the solar districts (i.e. a recruitment target of 20% of the inhabitants of the solar districts).

## 4.3 Individual battery management

### 4.3.1 Introduction: Scope of tests

Within the framework of the NiceGrid Smart Grids demonstration project, the use of a residential battery is experimented in response to various requests from grid managers.
This battery is one of the levers allowing implementation of the Use Cases defined for the project:

- Reduction in peak power;
- Massive introduction of PV.

[26] Active: actually take part in the experiments (the technical requirements for the customer's subscription are met)

Management of this battery is performed by a local smart system (EDELIA box) itself servo controlled by a remote platform managing demand.

Depending on the request from the PFD, the local smart system can use three battery management strategies:

1. Default mode (no load);
2. Preparation mode (SOC to be reached by a given date);
3. Modulation mode (charge or discharge power to be applied – insofar as possible – during a defined period of time).

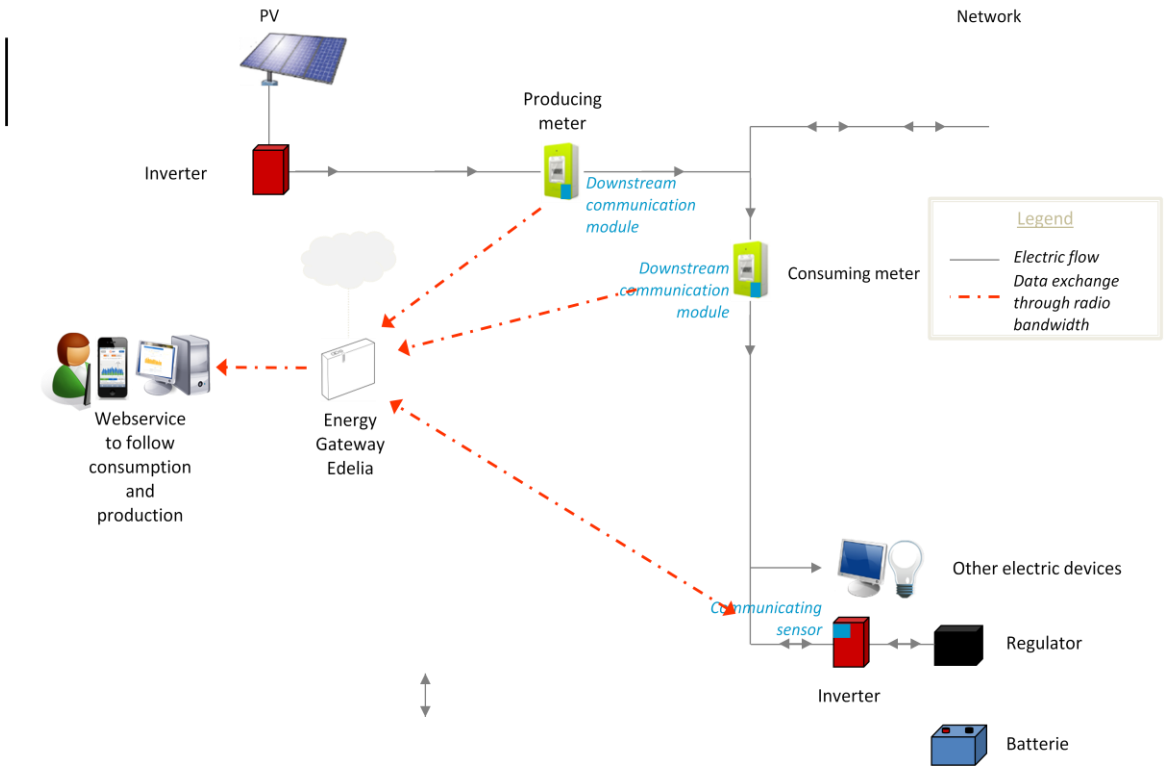
This document presents a summary of the tests underway at EDF Lab les Renardières in the "Multi-Energy Home" laboratory and the ConceptGrid tests at EDF Lab les Renardières, which validate the operation of this local smart system before it is deployed on the experimental sites.

## 4.3.2 Description of tested equipment

The tested system consists of:

- an electrochemical storage system (INTENSIUM HOME) from SAFT;
- a 6.0H SUNNY ISLAND inverter system from SMA;
- the local smart system, itself consisting of:
    - an EDELIA gateway;
    - a TIC reader-transmitter (MC11) supplied by EDELIA.

Diagram presenting all the storage and management equipment deployed:



- **SAFT 4 kWh Li-Ion battery**

The electrochemical storage device is an NCA (Nickel Cadmium Aluminium) type Li-Ion battery, the main characteristics of which are as follows:

- Capacity: 82 Ah (4 kWh) (the charging time of the battery depends on the power load)
- 48 VDC (2 SYNERION 24V modules in series)
- Pmax discharge: 7,6 kW
- Pmax Charge: 4 kW
- Efficiency (charge or discharge) : > 95 %.

The 3 modules (2 SYNERION + 1 BMM) are contained in a cabinet which comes in 2 versions for the project: indoor version (doc. [4]) and outdoor version (doc. [5]).

Indoor version :

- IP20 – 95 kg ;
- Gas Management System ;
- Cables on the top.

Outdoor version :

- IP54 – 95 kg ;
- Heating system and ventilation ;
- Cables on the bottom.

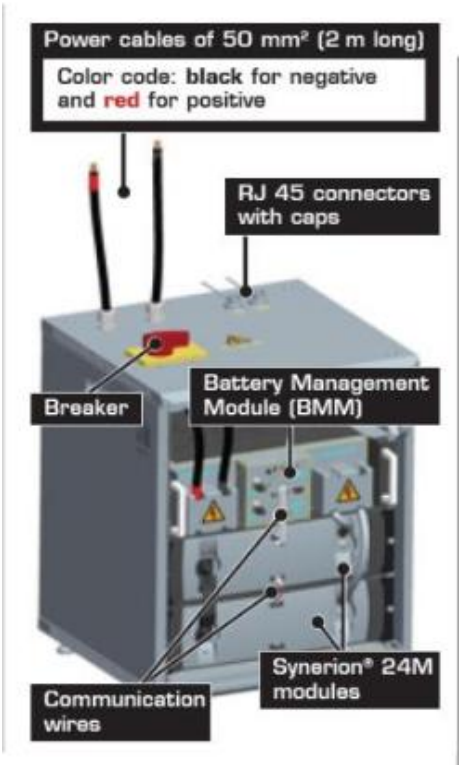

Power cables of 50 mm² (2 m long)
Color code: black for negative and red for positive
RJ 45 connectors with caps
Breaker
Battery Management Module (BMM)
Synerion® 24M modules
Communication wires

*Figure 78. SAFT "indoor" battery*

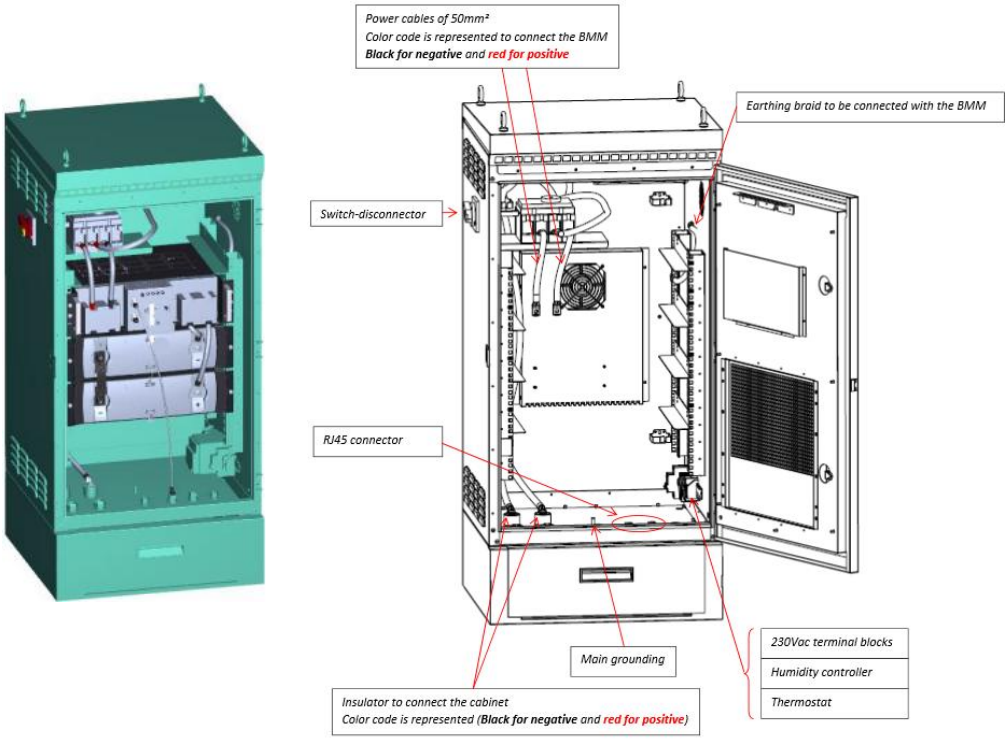

Power cables of 50mm²
Color code is represented to connect the BMM
Black for negative and red for positive
Earthing braid to be connected with the BMM
Switch-disconnector
RJ45 connector
Main grounding
230Vac terminal blocks
Humidity controller
Thermostat
Insulator to connect the cabinet
Color code is represented (Black for negative and red for positive)

*Figure 79. SAFT "outdoor" battery*

- **SMA Sunny Island inverter**

The SMA inverter serves as the interface between the battery and the electricity grid. In particular, it is this device which controls battery charging or discharging according to requests from the gateway, taking into account the real-time operating parameters provided by the battery itself.
It is a 6.0H Sunny Island inverter equipped with its wired remote control SRC (Sunny Remote Control) (cf. documents [6] and [7]):

- Rated power (AC): 4.6 kW;
- Rated input DC voltage: 48 V;
- Battery types: Pb (FLA,VRLA), Li-Ion;
- Capacity range of Li-Ion batteries 50 to 10,000 Ah;
- European efficiency: 94.3%
- Consumption:
- Standby: < 4 W;
- Open circuit and discharge: < 27 W

*Figure 80. Sunny Island and Sunny Remote Control (SRC)*

The SRC has a slot for insertion of an SD card on which the inverter records its operating data at 1 min. intervals and events such as alarms.

- **EDELIA gateway**

The gateway serves as an interface between the PFD and the local system. It also contains the algorithm for battery management according to local parameters (consumption, condition of the battery, etc.) and requests coming from the PFD.

It communicates (cf. document [2] § III):

- via Internet (Ethernet cable link to the internet customer's box or GPRS) with the PFD;
- via an RS485 cable (SMANET protocol) with the SMA inverter (connection to an USB port).
- via radio (EN13757-4 (868MHz)) with the TIC MC11 reader, in Receive mode only.

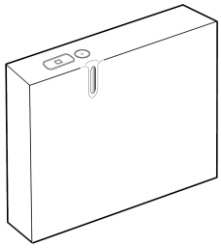


*Figure 81. EDELIA gateway*

- **EDELIA TIC reader: MC11**

The TIC reader-transmitter (MC11) is connected to the customer remote information (TIC) output of the ERDF electronic meters. It is compatible with the communicating meters “Linky” (used in the context of NiceGrid). It recovers the information sent over this output such as the energy set point, the current tariff period, etc., which it sends in broadcast mode to the gateway.
It communicates via an encrypted one-way radio link with this gateway.
A LED indicates the status of the TIC link, for a few minutes.

Some technical characteristics (cf. document [2] § III):

- Operation on non-replaceable battery;
- Service life: about three years;
- Radio protocol: EN13757-4 (868MHz);
- Data sending: every 3 min.
- Radio range: about 30 metres indoors

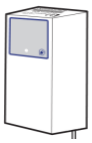


*Figure 82. TIC MC11 reader*

- **Operating principle:**

Depending on the requests from the PFD, the current tariff period and the various energy flows on the site, the gateway calculates set-point battery charge and discharge values which it sends to the inverter so that the latter may apply them if they are appropriate for the limits of the inverter-battery system.
Otherwise, the inverter may stop charging or discharging, or else change the set-point value to make it compatible with the operating limits.
There are three possible management modes:

1. **Default mode**: No request is made by the PFD. In this case the gateway applies 2 strategies depending on whether the customer has a PEAK/OFF-PEAK or BASE-LOAD tariff.
   In the case of a PEAK/OFF-PEAK tariff the battery is charged in off-peak hours and discharged in peak hours according to the customer's consumption.
   For a BASE-LOAD tariff, no charging or discharging is performed.
   In all cases, the gateway ensures that the battery's SOC is at SOC_0H at 00h00 every day

2. **Preparation mode**: The PFD sends to the gateway a target SOC to be reached before the end of the allotted period while taking into account the customer's consumption.
3. **Modulation mode**: In this third mode the PFD provides a set-point value in charge or discharge power, during a defined period of time, that the gateway tries to comply with as well as possible depending on the customer's consumption.

The following table[27] summarizes these various operating modes:

| | Customers with peak/off-peak tariff | Customers with Base-load tariff |
|---|---|---|
| Default mode | ▪ To charge the most possible during the peak hours<br>▪ To discharge the most possible duringt he off-peak hours | ▪ To limit the customer loss<br>▪ To maintain the battery level around $SOC_{00h}$ |
| Preparation mode | ▪ To charge or discharge the battery to reach $SOC_{target}$<br>▪ To respect the charge/discharge hours | ▪ Charge or discharge the battery to reach $SOC_{target}$ |
| Modulation mode | ▪ To follow as well as possible the PFD set-point | ▪ To follow as well as possible the PFD set-point |

Protection mechanisms

**High SOC protection**

When the battery's SOC reaches the value SOC_MAX, the gateway stops battery charging, unless a higher preparation target SOC overrides this rule.

**Low SOC protection**

When the battery's SOC reaches the value SOC_MIN, the gateway stops battery discharging, unless a lower preparation target SOC overrides this rule.

**Critical SOC protection**

The gateway has a protection mode when the SOC reaches a critical low threshold (SOC_CRITICAL): whatever the operating mode (default, preparation, power), it gives the inverter the order to recharge the battery to a power of FLOATING_POWER or higher value if the current mode requires recharging the battery.

This recharging is stopped when the SOC reaches SOC_MIN.

Moreover, the inverter also has its own parameter determining the minimum value of the SOC authorizing battery discharging. Below this value, which is set to a point lower than the SOC_CRITICAL, the inverter stops any discharging.

Finally, below 3% for more than 5 min., the inverter is switched off and a manual action is

[27] Source: EDELIA

necessary to restart it.

**No circuit breaker tripping**

When the battery is recharging, it consumes energy on the grid. This consumption is added to that of the customer in whose home the battery is installed. Charge management must take into account the total consumption of the house (with the battery) to prevent exceeding the customer's contract power and thus causing circuit breaker tripping of the installation.
When it receives consumption data from the MC11 (every 3 min. in theory), the gateway checks that the power consumed does not exceed the contract power given by the Linky meter and adjusts the battery's set-point charge value.
Since the time interval (3 min.) is too high to ensure no circuit breaker tripping in real time, a safety factor is applied to the battery's set-point charge value and a safety margin is applied to the maximum power to reduce the risk.

**No injection**

Conversely, when the battery is discharging, it must not inject energy into the grid. The power supplied by the battery must not exceed that consumed by the customer.
When it receives consumption data from the MC11 (every 3 min. in theory), the gateway checks that the power injected into the grid is zero and adjusts the battery's set-point discharge value.
Since the time interval (3 min.) is too high to ensure no injection in real time, a safety factor is applied to the battery's set-point discharge value and a safety margin is applied to the reinjection threshold to reduce the risk.

**Limiting operating losses**

The inverter's power supply is provided by the battery.
The inverter specifications indicate own consumption of:
< 27 W in normal operation;
< 4 W in standby mode.
To limit operating losses, the inverter is placed in standby mode when no charge or discharge is requested of the system.

**Data reporting**

The gateway reports every hour the collected data :

- from the Linky meter via the MC11 with a 3 mn interval (extraction and injection set point, current tariff period, date, etc.); the PDF receive the collected data every 10 mn.
- from the inverter with a 1 mn interval (status: operation, standby, warning, error, SOC, current P charge or discharge, power meters, etc.).

In the event of a warning or error message sent by the inverter, it transmits the error code in real time.

## ▪ Summary of gateway prototype development tests

In early 2014, development tests for a prototype of the gateway were performed in the MM-E laboratory.
The main objectives of these tests were to:

- Validate the choice of management algorithm in order to finalize its specifications;
- Test in real time the SMANET communication protocol with the inverter (since EDELIA has no inverter).

The prototype consisted of a laptop computer under Windows on which the algorithm was run. Communication with the inverter was implemented via a radio interface (a USB key at the computer end and a box with an RS485 interface at the inverter end) supplied by WATTECO.
Since WATTECO has pulled out of the project, a cable-connected communication solution has had to be examined and EDELIA has had to include management of the SMANET protocol in its software.

Since the MC11 box of the prototype was not configured to read the standard TIC, the Linky meter was configured as an historical TIC. In this mode, some data, especially those relating to injection, are not present.

A gateway prototype then replaced the computer, and this led to the following architecture, which has become definitive for the validation tests:

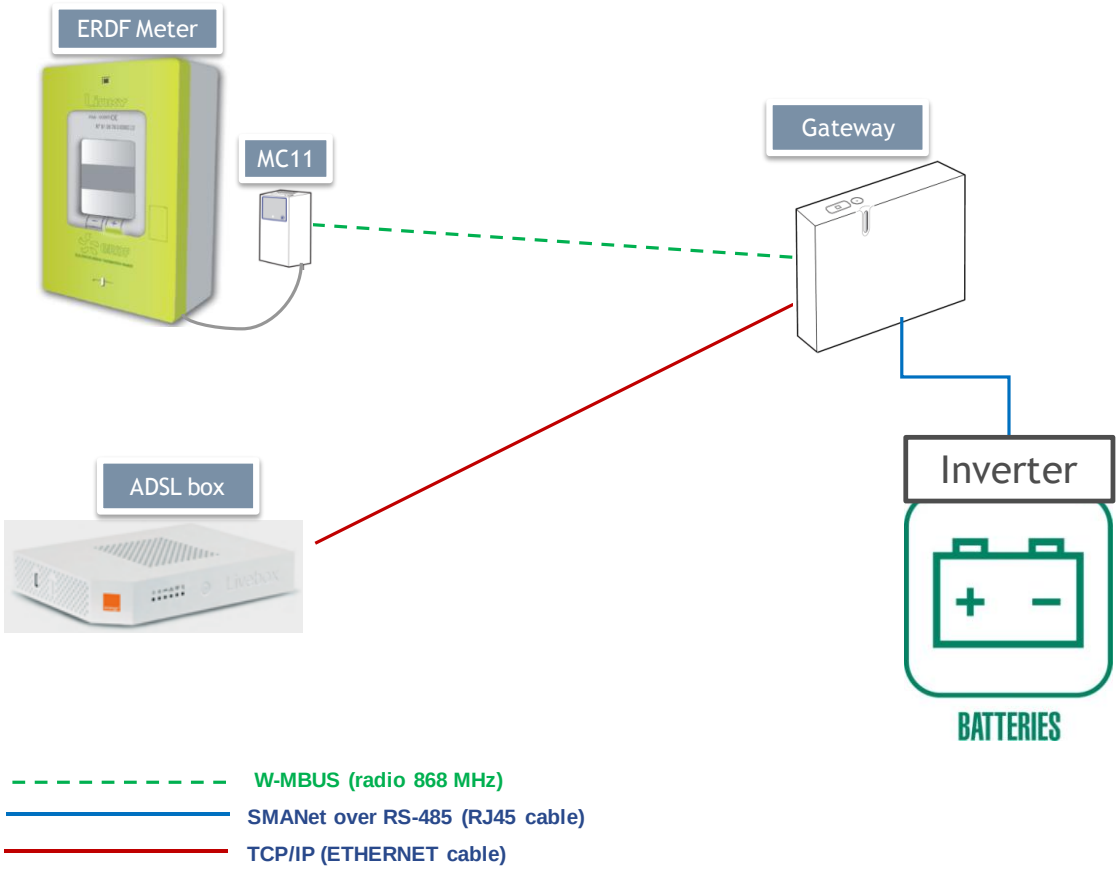



*Figure 83. Final prototype architecture (doc [3])*

These tests made it possible to check that the management algorithm corresponded to the definition of the need (doc. [2]), and in particular battery management in the various modes.

They also contributed to:

- Determination of connector systems and the physical characteristics of communication with the inverter.
- Consolidation of the data exchanged between the gateway and inverter (operating parameters, operating values, alarms);
- Improvement of alarm management between the battery and the inverter (entailing an update of the battery parameters by SAFT);
- Definition of the TIC data allowing monitoring of the site's extraction and injection.
- Adjustment of the algorithm's operating parameters (cf. Table § 0).

During these tests the decision was taken to eliminate the three-phase sites from the scope of the experiment, since overall TIC data, and not phase by phase, cannot ensure satisfactory functioning of the algorithm.

These tests also highlighted problems of reliability regarding TIC data transmission between the MC11 and the gateway.

Reception problems were a priori attributed to the disturbed environment of the laboratory, but it was decided to investigate this point in greater detail during the validation tests.

The limitations of the prototype compared with the planned final version (historical TIC, poor transmission between the MC11 and the gateway) meant that improvements were considered in order to increase the robustness of the algorithm in degraded operation.

### *4.3.3 Description of the installations and the test instrumentation*

Two installations have been made to operate the test[28](see pictures in Annexe 2).

- **In the Multi-Energy Home (MM-E) laboratory**

This laboratory has an acquisition system which measures continuously (every 10s) the average battery charge and discharge power values, and installation injection and extraction.
The electric power supply is single-phase. The Linky meter, of the L+G brand, is configured in PEAK/OFF-PEAK tariff with off-peak hours from 11.00 pm to 7.00 am.
The battery cabinet used is of the indoor type.
The following diagram shows the installation in the laboratory.

[28] An indoor battery and a outdoor battery have been tested in EDF Labs (cf. Figure 84 and figure 85).

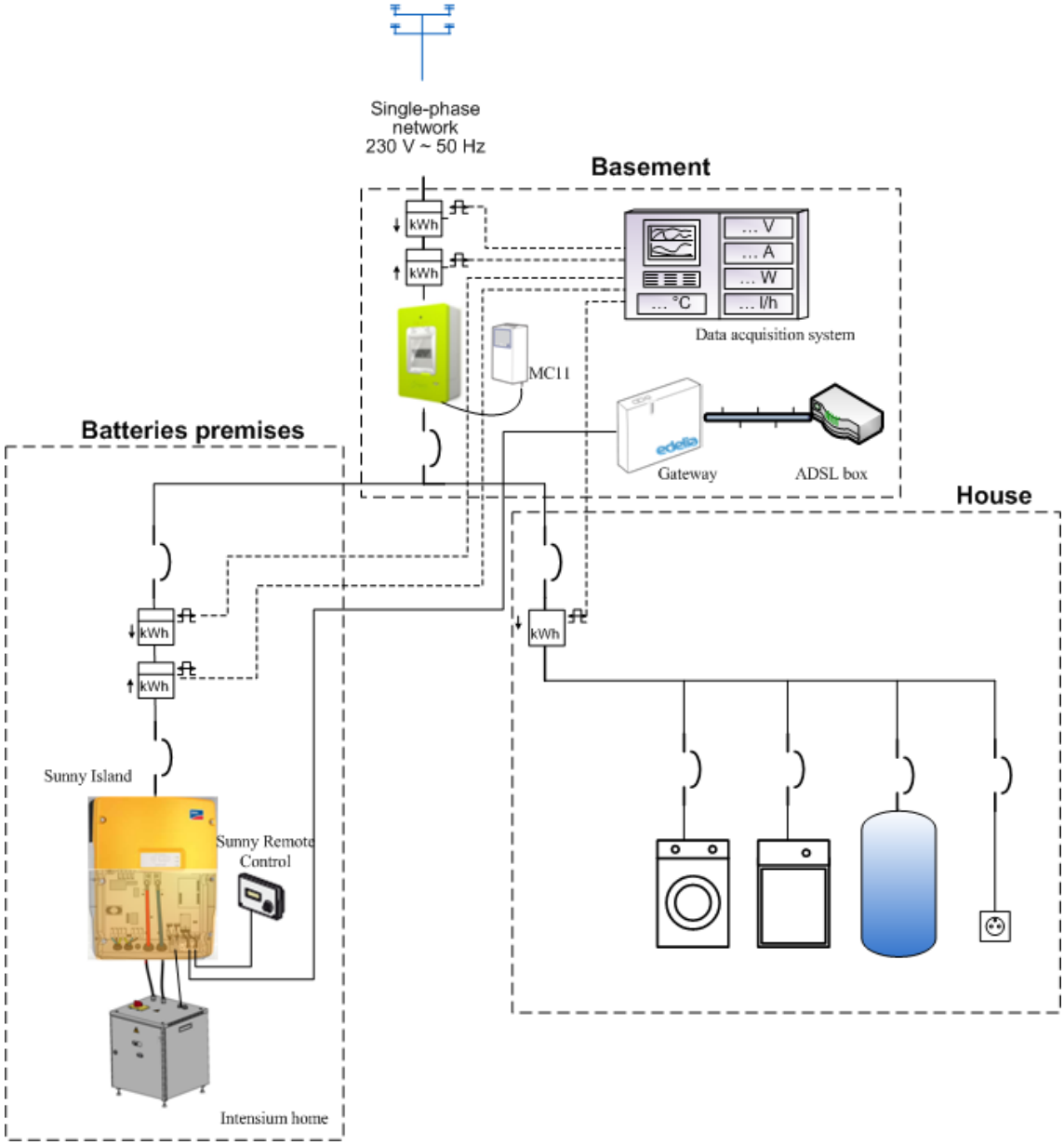



*Figure 84. Single-line diagram of the installation in the MM-E laboratory – Indoor battery*

- **In the ConceptGrid laboratory**

This installation is not monitored. Only the information reported by the EDELIA gateway and the data recordings of the inverter on the SD Card of the SRC are available.
The electric power supply is single-phase. The Linky meter, of the ITRON brand, is configured in base-load tariff.
The battery cabinet used is of the outdoor type.
This installation was used mainly for the **operating tests and certain limit tests**.

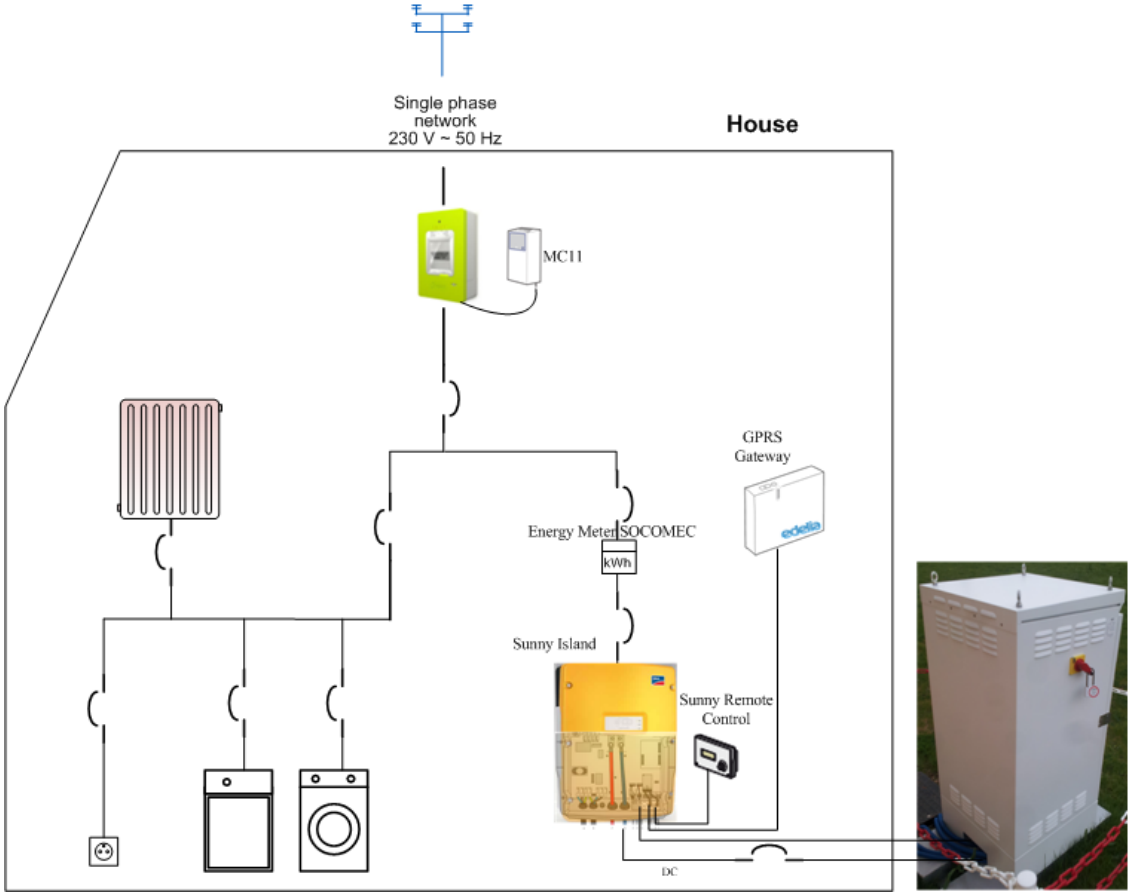



*Figure 85. Single-line diagram of the installation in the ConceptGrid- Outdoor battery*

## 4.3.4 Test conditions

The following table lists the various operating parameters of the management algorithm incorporated in the EDELIA gateway as they were set at the start of the tests.
During the tests, adjustments were made to these parameters.

| Field Name | Description | Value |
|---|---|---|
| **SOC_CRITICAL** | Critical SOC before emergency stoppage (at 3%) of the inverter | 8% |
| **SOC_MIN** | Minimum SOC for discharge | 15% |
| **SOC_MAX** | Maximum SOC for charge | 90% |
| **SOC_0H** | Reference SOC at midnight | 15% |
| **CHARGE_MARGIN** | No-circuit-breaker-tripping margin | 500W |
| **DISCHARGE_MARGIN** | No-reinjection margin | 200W |

| | | |
|---|---|---|
| **MIN_CHARGE_POWER** | Min. charge power | 100W |
| **MAX_CHARGE_POWER** | Max. charge power | 4000W |
| **MIN_DISCHARGE_POWER** | Min. discharge power | 100W |
| **MAX_DISCHARGE_POWER** | Max. discharge power | 4500W |
| **FLOATING_POWER** | Floating charge power | 500W |
| **SOC_STRIP_INF** | Lower SOC strip<br>(allowance for self-discharge) | 5% |
| **SOC_STRIP_SUP** | Upper SOC strip<br>(allowance for hysteresis in charging) | 2% |
| **DEFAULT_POWER_PCT** | Percentage of power in default mode | 75% |
| **WD_TIMEOUT** | Watchdog tripping timeout (minutes) | 10mn |

*Figure 86. Single-line diagram of the complete installation in the laboratory*

### 4.3.5 Test procedure

The first tests concerned the reliability of transmission between the MC11 and the gateway.
During these tests the Linky meter of the L+G brand was replaced by a meter of the ITRON brand, since problems of compatibility were detected on the MC11/Landis+Gyr meter pair (cf. § □).
Since the inverter was originally planned for the German electricity grid, SMA provided us with a procedure to change certain decoupling parameters to bring it into line with French regulations.
These adjustments were possible only after updating the SUNNY ISLAND software from version 3.0 to version 3.1.
Note that for the prototype tests the inverter software version was number 2.3.
During the tests, improvements were made to the management algorithm, in particular regarding the following aspects:

- Floating charge;
- Robustness with regard to possible inverter malfunctions.

The following table summarizes these changes.

| Description of change | Firmware version | Specifications version | Date of deployment (2014) |
|---|---|---|---|
| Correction of an UTC/Local time difference causing off-peak charge 2 hours late | 1.0.2 | < v3.0 | June |
| Correction of a problem of collection punctuality | 1.0.2 | < v3.0 | June |
| Correction of a FedInSocStr/Stp initialization problem | 1.0.3 | v3.0 | 20 August |
| Reactivation of FedInSpntCom at each starting of the inverter | 1.1.3 | v3.0 | 20 August |
| Reduction of floating charge power | 1.1.3 | v3.0 | 20 August |

*Figure 87. Table of changes in the management algorithm*

### 4.3.6 Test results and analysis/interpretation

The list of tests is given below together with their interpretation when they have been completed. The complete performance report at the date of the document is presented in Appendix 1.

- **Operating tests**

**Default operation**

On the BASE-LOAD tariff, default operation, which involves keeping the battery at a SOC of 15% (SOC_0H), causes, in nominal operating conditions, regular so-called "floating" recharging to compensate for the system's self-discharge.

We note:

- An excessive recharge power given the SOC to be achieved (+5% in the test configuration). => change in the algorithm to manage the "floating charge" concept with an appropriate power.
- A discharge sometimes follows the charge when an SOC jump occurs after stopping charging. => increase in the SOC_STRIP_SUP parameter, the role of which is to allow for these SOC jumps.

In PEAK/OFF-PEAK tariff the operation which involves charging in off-peak hours and then discharging in peak hours highlighted the following behaviour, specific to the test sites:

- In off-peak hours, charging is very rapid (<1 hour) because the consumption profile of the test sites is low.
- In peak hours, discharging is slow and even insufficient (>15 hours) because the consumption profile of the test site is low or even no consumption can be observed

This second point made it possible to observe regularly the response of the algorithm concerning non-injection.
Concerning the first point, these results led to the proposal of a reduction in the charge/discharge factor in order to reduce the risks of circuit breaker tripping on the sites of customers whose consumption profile will be more erratic and higher.

**Preparation mode**

Several preparation orders were sent at 90% or 15% of SOC. In satisfactory radio reception conditions, all the orders were carried out. The same observations as in the default mode were made in the MM-E where the low and very erratic consumption lengthened the time before reaching the set-point value, although without exceeding the allotted time.

**Modulation mode**

In modulation mode, the system must follow a fixed set-point power value over a given period within the limits of the constraints of the inverter/battery and the instantaneous consumption of the site.
As for the other modes, compliance with the set-point value in charging posed no problem. In discharging, the set-point value was not always able to be complied with given the low consumption in the MM-E.
However, set-point value following was regularly interrupted by tripping of the watchdog caused by

the absence of data reception from the MC11 for more than 10 minutes.

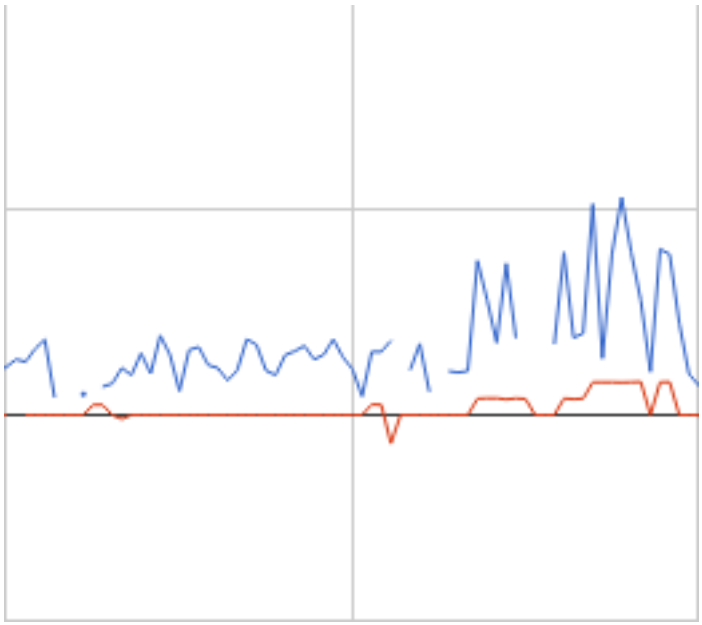


*Figure 11. Modulation punctuated by safety stoppages*

This limitation is the direct consequence of the radio problems encountered between the MC11 and the gateway.

**Mode sequences**

Sequencing of operating modes posed no problems during the tests and the sequence took place satisfactorily.

- **Limit tests**

**High SOC**

The high SOC limit is directly secured by the operation of the battery inverter system which cannot be charged beyond 100%. For reasons of efficiency, however, the algorithm stops all charging at 90% (SOC_MAX).

**Floating charge**

The floating charge is designed to offset losses due to self-consumption by the inverter and the battery. It is started whenever the SOC diverges by more than 5% (SOC_STRIP_INF) below the current SOC set-point value.

When the SOC goes below the bar of (SOCtarget-5%), the battery is recharged up to SOCtarget.

In its initial version, the algorithm did not specifically define the floating charge. This was implicit due to failure to reach the set-point value. The power of the charge was therefore the default power used in default or preparation mode and hence oversized for recharging the battery by 5% (200Wh).

A change was therefore made to limit the power in the lower SOC strip to 1000W (FLOATING_POWER). Under these conditions, a floating charge lasts about ten minutes.

**Safety charge**

When the SOC goes below the 8% bar, the battery is recharged up to 15%.

The same behaviour as for the safety charge is observed:

- When the gateway stops recharging at 15%, it may occur that a SOC jump raises this value to 18%, which generates a battery discharge of up to 15%, the operating mode being the default mode.

The change for the floating charge above was likewise applied to limit this phenomenon.

**No circuit breaker tripping and no injection**

During the tests, injection periods were observed. Operating analysis showed a good response of the system to injection (appropriate reduction in the discharge). However, the response time did not make it possible to completely prevent injection.

A test is underway to place the installation in a critical case for circuit breaker tripping, and the results should be similar.

These observations are due to the MC11 sending period of 3 minutes, possibly extended in the event of reception problems, which cannot fully ensure non-injection or no circuit breaker tripping of the installation.

In order to prevent these two phenomena, the safety margins and factors should be adapted in order to reduce the risks of placing the system in a critical situation.

**Low set-point values**

A management inhibition function when the set-point value is low can place the inverter in a linear zone.

When the charge or discharge set-point value is less than 100W, no order is sent to the inverter.

**SOC jumps**

During the tests, SOC jumps of between 1% and 2% were regularly observed. These were provided for as of the algorithm design stage and their management is ensured by the upper/lower SOC strips. However, larger jumps (up to 5%) were observed occasionally at the end of charging or discharging.

By increasing the upper SOC strip and reducing the floating charge power, the appearance of these jumps or their impact was able to be reduced.

## Communication

### *Use of PLC connectors*

Two PLC connectors were installed in the MM-E laboratory:

The first with an Ethernet link with the gateway;

The second connected to an output of the laboratory router.

No change in the system's operation was detected. In particular, communication with the PFD (reception of requests, data and alarm reporting) was not adversely affected.

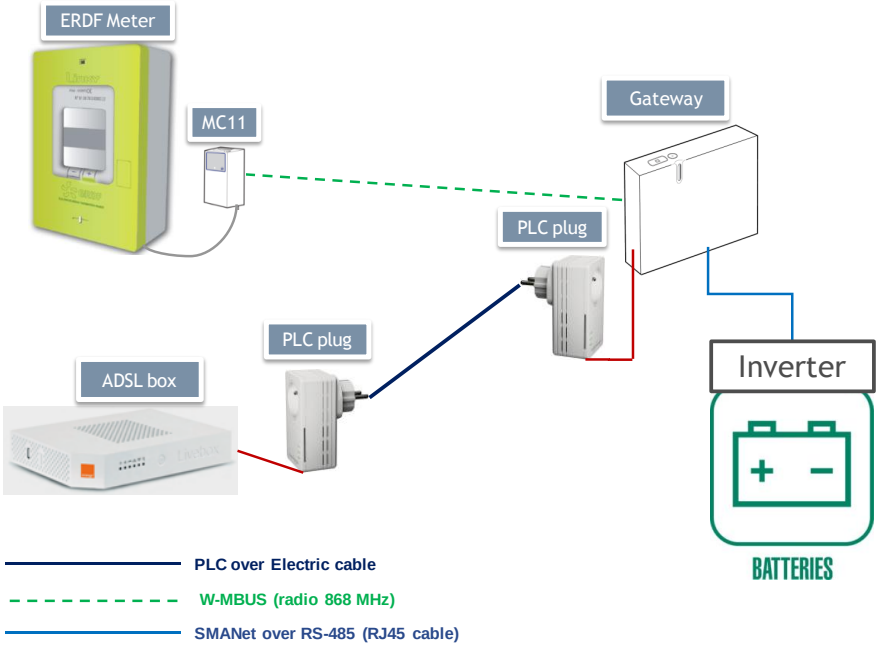



*Figure 88. Testing scheme with PLC plugs*

- ***Reliability between the MC11 and the gateway***

The first reliability tests revealed a problem of compatibility of the MC11 (detection of the TIC signal) with the Linky meters of the Landis+Gyr brand.
In one of the laboratories, the L+G Linky meter was replaced with an ITRON meter.
Measurements performed with a spy (supplied by EDELIA) gave the following frame reception averages:

| | Average | Maximum | Standard deviation |
|---|---|---|---|
| MM-E | 00:05:43 | 00:36:00 | 00:04:16 |
| ConceptGrid | 00:05:39 | 00:41:59 | 00:04:10 |

The various analyses performed concluded that radio problems are caused by a combination of various factors:

- Radio environment (the risk of radio collision is especially high when the number of sensors on the frequency band is high).
- MC11/Gateway distance (since the power of the signal weakens based on a factor of the square of the distance).
- Length of the sent frame (the standard TIC frame being longer than an historical TIC frame, the risk of radio collision is statistically higher).

The operating conditions on the two test sites cannot be considered as critical (clean radio

environment, small MC11/gateway distance, target frame length).
Reception problems were regularly observed between the MC11 and the gateway. These are due to radio collisions on frames not retransmitted (broadcast transmission).
So far, no technical solution has been able to be provided.

- **Tests in degraded mode**
  - ***Loss of communication***

Gateway – Inverter

The cable between the gateway and the inverter was disconnected in 2 operating configurations (battery in charging and discharging mode): in these configurations the inverter stopped when the SOC reached its operating limits (100% for charging, FedInSOCStp for discharging).

Gateway – ADSL box

In the event of interruption of communication between the gateway and the PFD, the gateway correctly performs the instructions that it has stored in memory, then goes into default mode.

When communication returns, remote control can be resumed.

Gateway – TIC reader

A halt in reception of TIC frames by the gateway causes resetting of the set-point value by the gateway after the time defined by the Watchdog. An alarm is sent to the PFD.

Inverter – Battery

When the communication cable linking the battery to the inverter is disconnected, battery charging or discharging stops and the inverter goes to alarm mode.

  - ***Electric power outage***

This test has not yet been performed.

- **Data measurement and collection**

Energy measurements

Verification of the measurements reported via the gateway is in progress.

Alarms

During the various tests, the alarms related to malfunctions were suitably sent to the PFD.

In particular, one of these alarms made it possible to identify a problem at the battery level which is being dealt with.

Efficiency of the inverter/battery system

The overall efficiency of the complete system (including the power supply for auxiliaries) will be calculated at the end of the tests.

## 4.4 Conclusion

The implementation process of the PV panels was satisfactory on the following points:

- In its technical assistance measures, the support of the CSTB is a major asset for EDF. This support is a real guarantee of trustworthiness and neutrality which encourages customers to agree to take part in the project.
- In the content of the commercial offer aiming to reduce the payback period for the PV installation to at most 6 years;
- In performance of the works, since worksite visits and audits effectively made it possible to eliminate negligent installers and nonconforming equipment.

However, the economic and political environment is not conducive to PV installation. The electricity buyback price fell constantly during the first two years of the project, as well as the tax credit from which customers benefit.

So we could not reach the objective for all the solar districts (30% of the district electricity consumption is bringing by the PV electricity production) but we reach it for 3 of them.
Two districts will benefit of a production of 24kWc for one (hostel) and an additional 140kWc for the other one (enterprise). The last district is expected to benefit 18kWc (6 housings).

However, the participation of people for management of the PV in their neighborhood was pretty good. Indeed, 14% of prospects have signed a participation agreement. So they agreed to store electricity in a battery, or engage their hot water or move their consumption during peak production.

Recruitment is continuing, in particular via a sponsorship campaign to reach about one hundred consum-actors in the solar districts (i.e. a recruitment target of 20% of the inhabitants of the solar districts).

Now, for the individual battery management system, the tests in progress are on the whole satisfactory and show no problems preventing satisfactory operation of the local smart system.
The latter satisfactorily manages the system's various operating modes (default, preparation, modulation).
Alarm reporting is performed correctly.
Management of limit cases (floating charge, high and low SOC threshold, etc.) and degraded modes means it is possible to limit cases requiring manual intervention to a minimum.
A few tests still have to be completed, in particular measurement verification, calculation of the system's overall efficiency, and electric power outage.
However, these tests revealed a few weaknesses of the system:

- Incompatibility of the MC11 with the version 1 Linky meters of the Landys + GYR brand;
- Unreliability of broadcast sending of TIC data by the MC11.
- Time interval of 3 minutes for these data, making it impossible to ensure non-injection

and no circuit breaker tripping (unless, for the latter point, the customer's contract power is increased or the battery's charge power is severely limited);

To ensure the end of 2014 deployment, management solution presented in this document will be deployed on ITRON meters and will limit the power of the batteries. The project team is considering the implementation of a rapid feedback loop to provide a solution to ensure the non-injection or not exceeding contracted power and the house PV production.

These tests also made it possible to detect:

- An inverter management problem (following the transition to version 3.1) which must be corrected to ensure satisfactory operation of the system;
- A weakness of the battery which seems to accept rather excessive charge powers, and this can cause stoppage of the battery, requiring a manual intervention to start again.
- These two points are currently being dealt with.

The first summer (2014) was used to evaluate the performance of storage solution via hot water cylinders or displacement of consumption through price incentives. The second summer (2015) will also test the use of electric storage (planned deployment on winter 2014/2015).

# 4.5 Appendices

## *4.5.1 Appendix 1:*

| Family | Name | Status | Result |
|---|---|---|---|
| Installation | Initial installation of the system | Completed | OK (V1.1.3) |
| Operation | Nominal operation of the default algorithm | Completed | OK |
| | Default charge/discharge power | Completed | OK |
| | SOC_OH verification | Completed | OK |
| | Nominal operation of the preparation algorithm | Completed | OK |
| | Nominal operation of the modulation algorithm | Completed | OK |
| | Mode sequences | Completed | OK |
| | Change or cancellation of orders | Completed | ***Warning*** |
| Limits | Verification of the SOC_MAX charge limit (or 90% < SOCTarget < 100% in preparation) | Completed | OK |
| | Verification of the SOC_MIN discharge limit (or 0% < SOCTarget < 15% in preparation) | Completed | OK |
| | Floating charge test | Completed | OK |
| | Safety charge | Completed | OK |
| | Minimum charge and discharge powers | Completed | OK |
| | Tests for no circuit breaker tripping and no injection | In progress | |
| | SOC jump measurements in cases of charge or discharge at high power | In progress | |
| | SOC jump measurements in cases of charge or discharge at low power | In progress | |
| Communication | ADSL communication via PLC connectors | Completed | OK |

| | | | |
|---|---|---|---|
| | Reliability of MC11/gateway communication | Completed | ***Warning (the 3 min. interval is not complied with)*** |
| Degraded | Loss of inverter communication in charging (preparation or modulation mode) | Completed | OK |
| | Loss of inverter communication in discharging (preparation/modulation mode) | Completed | OK |
| | Loss of inverter communication on standby | Completed | OK |
| | Loss of meter communication (MC11) | Completed | OK |
| | Loss of ADSL communication of the gateway during mode | NOT completed | |
| | Loss of ADSL communication of the gateway before a sequence (preparation, modulation) | Completed | OK |
| | Loss of Inverter-Battery communication | In progress | |
| | Grid power outage | NOT completed | |
| Data | Energy measurements | In progress | |
| | Alarm reporting to the PFD | Completed | OK |
| | Measurement of Inverter-Battery system efficiency | In progress | |

## 4.5.2 Appendix 2 : Pictures of the 2 installations

*Figure 89. Outdoor battery at the Conceptgrid laboratory*

*Figure 90. Indoor battery at the MM-E laboratory*

## 4.6 References


| | | |
|---|---|---|
| [1] | PE/E13/14/05: | Test programme - Tests for validation of the local smart system managing the residential battery – NiceGrid project (2014); |
| [2] | LV4-12-1: | Specification of the architecture and components (residential customers); |
| [3] | | NiceGrid - Edelia gateway algorithm specifications (v2.9 & v3.0); |
| [4] | SDU/MTH/BD/13-0650: | INDUSTRIAL BATTERY UNIT - SAFT Li-ion unit - Intensium Home – 4kWh battery system; |
| [5] | SDU/MTH/BD/13-2400: | INDUSTRIAL BATTERY UNIT - SAFT Li-ion unit - Outdoor Intensium Home – 4kWh battery system; |
| [6] | SI80H-60H-IA-fr-20W: | Installation instructions - SUNNY ISLAND 6.0H / 8.0H; |
| [7] | SI60H-80H-BE-fr-20W: | Operating instructions - SUNNY ISLAND 6.0H/8.0H - SUNNY REMOTE CONTROL; |